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REPORT ON PRELIMINARY STUDIES OF POLLUTION IN BISCAYNE BAY

To

FEDERAL SECURITY AGENCY
PUBLIC HEALTH SERVICE
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by

Hilary B. Moore, Ilmo Hela, Ernest S. Reynolds, J. Kneeland McNulty,
Sigmund Miller, Clarence A. Carpenter, Jr.

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Coral Gables
Florida

F. G. Walton Smith
Director

ML 9054

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JANUARY 1955

SUMMARY

1. The ecological effects of sewage pollution, while understood in general terms for fresh-water streams, remain largely unexplored in estuaries.

2. The fact that Biscayne Bay, after many years of pollution, will cease to receive sewage effluents on 1 July 1956 offers an unique opportunity to conduct ecological experiments on a broad scale, both before and after the outfalls are sealed. The work involves:

   a. A detailed exhaustive preliminary study of the various factors, and

   b. A study of certain factors selected as a result of the earlier work to be carried out over a period extending beyond the time when the sewage pollution ceases.

3. Data for a study of water exchange in the bay have been collected and tentative conclusions have been drawn, as follows:

   a. The region studied has an area of 25.30 square miles (70.42 x 10^7 square feet), an average depth of 6.9 feet and a volume of 48.33 x 10^8 cubic feet at low tide and 61.45 x 10^8 cubic feet at high tide. Mean high tide volume is thus about 27% greater than mean low tide volume. The mean contribution from fresh-water rivers and canals is less than 5% of this.

   b. The tides are mainly semi-diurnal.

   c. The shallower areas of the bay constitute a one-layer system, although the main ship channel is sufficiently stratified to constitute a two-layer system except during the later part of the flood tide, when it is sufficiently mixed to constitute a one- layer system.

   d. Except for the Miami River mouth and immediate vicinity, where conditions are septic, oxygen saturation values well above the 40% level are generally found throughout the bay.

   e. A large area with little tidal flushing lies between 79th Street and Venetian Causeways. Flushing extremes occur between the mouth of the Miami River and Fisher Island, in particular. The high salinity range less than one-half mile East of Bayfront Park indicates that relatively pure ocean water penetrates this highly polluted location of the bay twice each day.

4. A chart has been prepared which shows salinity ranges for the region.

5. Fathometer records and 12-hour current-salinity studies have been made at all entries and exits of the bay. Additional 12-hour current-salinity field studies have been completed at 45 stations within the bay. Analyses of these data are incomplete.

6. Data from both the hydrographic and bacteriological studies indicate a deterioration of bay conditions since the last pollution survey, conducted in 1949.

7. Data from phosphorus determinations (phosphate-phosphorus, particulate-phosphorus, dissolved phosphorus, dissolved organic phosphorus and total phosphorus) indicate that these components, originally higher in sewage-laden water than in the cleaner waters nearby, are rapidly diluted by tidal action. Areas north of Venetian Causeway along the Miami shoreline show maximal values, the combined resultants of little tidal mixing and, probably, active regeneration of these components in excess of local biological requirements. That part of the phosphorus components supplied directly and indirectly by sewage alone probably can be estimated by additional studies after sewage no longer enters the bay.

8. A bacteriological survey conducted at key stations throughout the bay has permitted the following:

   a. A study of the nature of wide tidal and distributional fluctuations of MPN graphs of which are included.

   b. The development of a new concept, the Pollution Effectivity Index, as an additional analytical tool in such studies. The Index is a graphical integration of MPN changes throughout a 12-hour tidal cycle. It was developed to fill the need for a quantitative statement of the continuity and intensity of pollution despite rapid and extensive fluctuations of MPN values at most locations in the bay. Its effect is to provide a truer statement of the effective environment to which organisms in a locality are exposed by de-emphasizing peak values of short duration.

   c. Simultaneous analysis of many parameters in conjunction with MPN results by the use of accompanying hydrographic, chemical and plankton data.

9. Most types of macroorganism populations show marked gradients correlated with intensity of pollution. In general, organisms are relatively scarce at the enters of pollution, much more abundant in areas of moderate pollution, and then increase to normal abundance in clean water. A summary of each of these parameters follows:

   a. Plankton volumes were markedly reduced in the most highly polluted areas and did not show abrupt increases on either side of such areas but increased slowly to maximum values at stations of moderate pollution and high phosphorus content.

   b. Fouling intensity dropped abruptly in the most highly polluted areas and was maximal in areas of little tidal mixing and high phosphorus content such as stations north of Venetian Causeway. It was minimal in areas of clean water and low phosphorus content, such as south of Rickenbacker Causeway.

   c. No plants and few animals were found on the bottom in areas of heaviest pollution. Immediately outside these areas, bottom animals showed sharp increases, these maxima tapering off roughly in proportion to the gradual appearance of bottom plants as pollution decreased.

   d. No conclusive evidence was found on the effect of sewage pollution on marine borer attack rate. This parameter seemed to be more dependent on the advection of larvae than on pollution factors.

   e. A table listing species of fish caught in polluted areas, additional species known to occur in polluted areas, and other species caught in small numbers in the Biscayne Bay gill net commercial fishery (possibly in polluted waters) is included.

INTRODUCTION

The objectives of these investigations are a large-scale attack on the overall problem of the occurrence of sewage pollution in Biscayne Bay, its dissemination throughout the area by tidal action and its impact on physical and biological conditions of the bay. These can be summarized as:

I. Water Exchange Studies (tidal mixing and flushing)

II. Chemical Studies

III. Bacteriological study of Public Health Parameters

IV. Macroorganism, and Ecological effects of sewage pollution with respect to available nutrients, plankton populations, the fouling complex, bottom flora and fauna, bottom materials, marine borers, commercial fisheries, productivity generally.

This is part of a long-term study planned to follow the steps in recovery, from pollution after the installment of the sewer system The plans call for studying over an extended period certain selected factors which have been determined by the more exhaustive earlier work.

The present report summarizes the first year of work in four sections: hydrography, chemistry, bacteriology and macroorganism studies. The area is estuarine in character and is complex in detail because of the numerous channels, islands, etc. It is therefore pertinent to have a clear understanding of the patterns of water movement in the area and the rate at which the various parts are subject to flushing. A general picture of this has been provided although considerable further analysis is called for before some of the details can be clarified. The bacteriological studies were designed to give an overall picture of present conditions and also to examine the validity of standard techniques as applied under conditions of rapid tidal fluctuations. As will be shown, some modification of the usual method of presentation of the data has been proposed. The chemical studies are an essential link in tracing the chain of events from the introduction of raw sewage into the area to the final modifications of the fauna and flora. As will be seen, the cycle of phosphorus - a key nutrient in the sea an it is on land - has helped to elucidate the problem. The studies of plankton and of fouling organisms have been carried further than those on bottom organisms and fisheries. The plankton, fouling and bottom studies fit into a consistent scheme of the effects of the pollution.

This is an interim report intended to show the present status of the work. The correlation between the various studies have not yet been fully worked out, nor have all the field studies been completed. The final section, therefore, is limited to a brief outline of some generalizations which are emerging, and which may be subject to modifications as the work proceeds.

Personnel directly concerned with this work are: Dr. F. G. Walton Smith, principal investigator; Dr. Hilary B. Moore, counsel and assistance throughout; Dr. Charles E. Lane, initial organization counsel and general supervision during first four months; Dr. Ilmo Hela, hydrographic supervision, field work 'under his direction by C. A. Carpenter, Jr, and J. Kneeland McNulty; Dr. Ernest S. Reynolds, bacteriologist, field work by Mr. McNulty; Sigmund Miller, chemist. assisted by Gloria Miller, Mr. Carpenter and Richard J. Leinecker; Mr. McNulty, coordinator ecologist, biological field work with the assistance of Mr. Carpenter. As is always the case, a large number of others, too numerous to include by name gave generously of their advice and assistance.

The conduct of this work has been made possible by a grant from the U.S. Public Health Service. Acknowledgments are gratefully accorded Dr. Charles E. Renn and other officials of the Public Health Service for their cooperation and advice in the planning and conduct of the work. Similarly thanks are due to Mr. David B. Lee of the Florida Public Health Service for his advice in the preliminary planning of this work.

REPORT ON PRELIMINARY STUDIES OF POLLUTION IN BISCAYNE BAY

I. WATER EXCHANGE STUDIES

Ilmo Hela, Clarence A. Carpenter, Jr., and J. Kneeland McNulty

A. General

This survey was begun November 11, 1953, and the field work was completed on September 19, 1954, All the original observations work sheets, etc, are filed in the Marine Laboratory. This hydrographic material is considered to be unique and very well suited for an analysis of conditions In a shallow estuary. Therefore, it is planned to perform these studies as a special problem should circumstances allow. Even without these more detailed hydrographic analyses, the water exchange study will give a very satisfactory background and explanation for several biological and bacteriological problems of the Biscayne Bay pollution.

The results of the latest study of Biscayne Bay pollution. previous to the present, are given in a mimeographed report:

> Joseph L. Minkin: Biscayne Bay Pollution Survey. May - October 1949. Florida State Board of Health, Bureau of Sanitary Engineering, Jacksonville, Florida, 1949

which is based, in part, on another:

> Donald L. Milliken: Report on Investigation of Water Resources of Biscayne Bay, Florida, May - August, 1949P U. S. Geological Survey in cooperation with City of Miami, Florida, 1949.

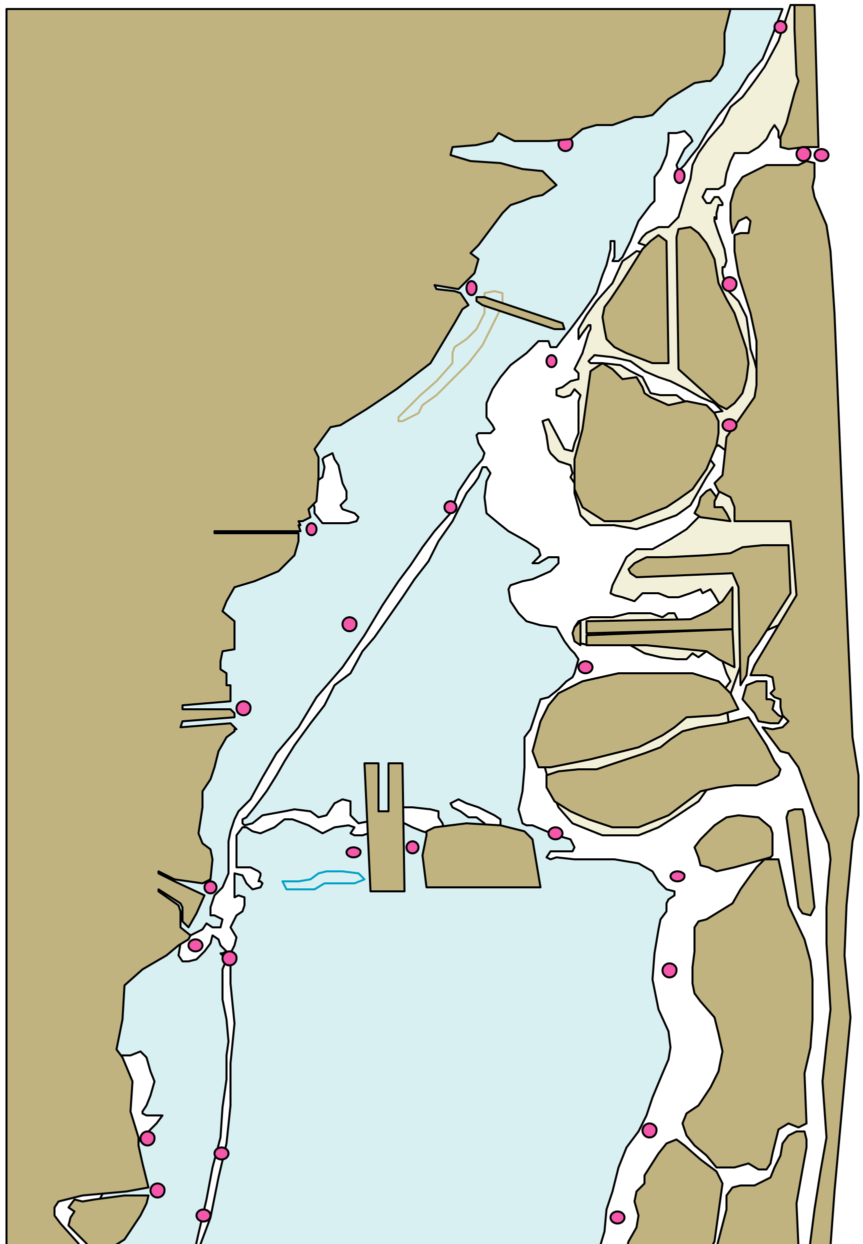
Both reports were available when planning this study. This helped in several ways for selection of the right methods for different approaches. To make comparisons possible, several of the same stations were used, as will be shown later in this report. Also in the final hydrographic analysis. when and if it is made, the above reports will be useful.

It seems to be correct to assume that the new sewage treatment system which is now being built for the Greater Miami area and which it is supposed, will eliminate the main part of the pollution in Biscayne Bay, will not affect essentially the features of water exchange in the Bay. Therefore. there will be no need to repeat this hydrographic study in the future when the biology of the Bay is studied anew.

B. Description of the Area Studied

Greater Miami, situated in Dade County at the southeastern coast of Florida, is protected from the open ocean by a string of islands (see Chart I*). Actually, only the northernmost part of Biscayne Bay is shown in the chart since pollution in the areas south of Rickenbacker Causeway and Virginia Key is relatively insignificant.

* In Chart I, the solid depth curve corresponds to the one-fathom line, the dashed one to the to the two-fathoin line. Due to technical difficulties, the Main Ship Channel between Government Cut and downtown Miami is not marked However, it is located just north of the one-fathom line which can be seen in the chart, The depths in the Main Ship Channel are about 30 feet.



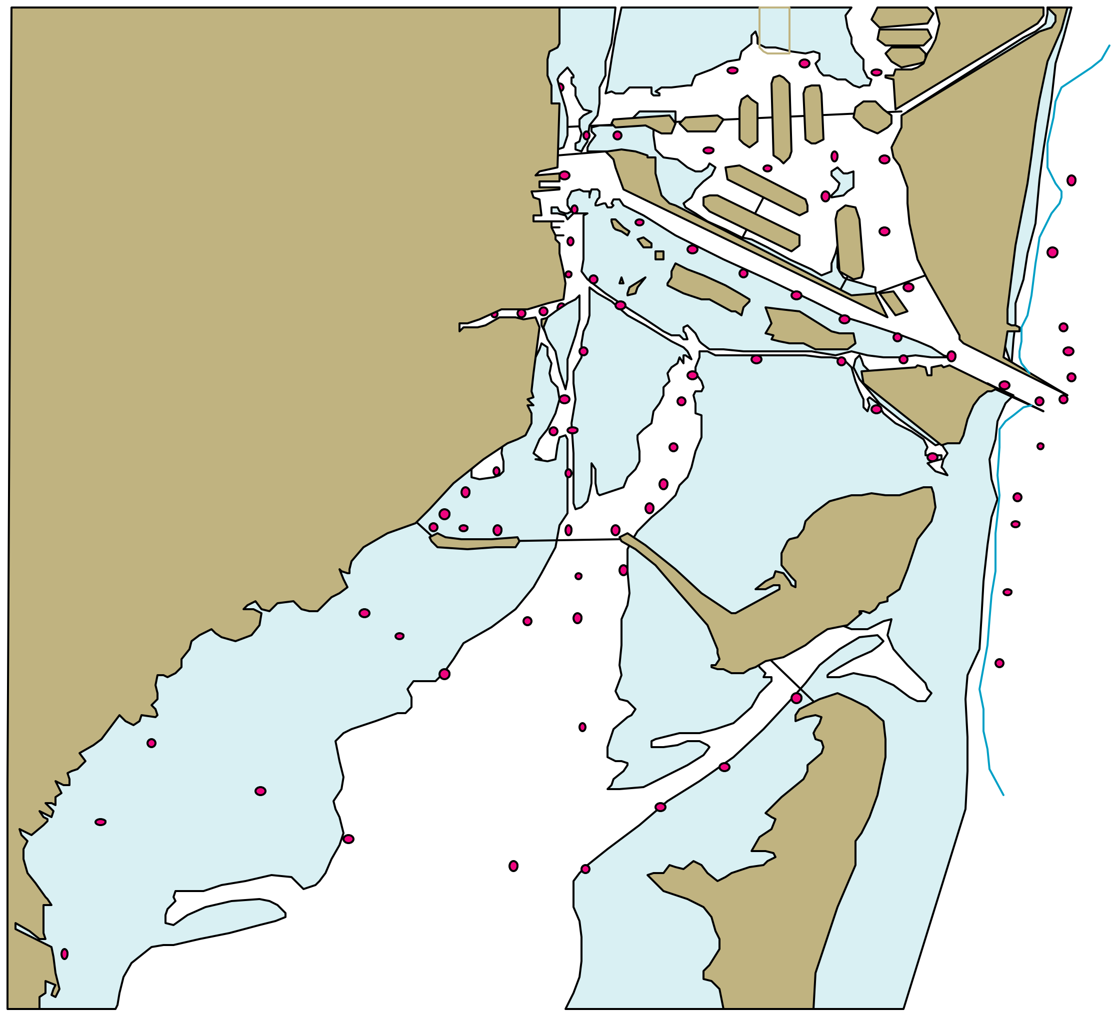


Table I. Areas, Mean Depth at Low Tide, and Volume of Biscayne Bay.

	AREA Description	ft^2	sq. mi.	Mean Depth at Low Tide	VOLUME Low Tide	High Tide
1	Light No. 12 to Broad Causeway	3.67×10^7	1.32	4	1.47×10^8	2.14×10^8
2	Broad Causeway to 79th Street Causeway	11.40×10^7	4.10	6	6.86×10^8	8.95×10^8
3	79th Street Causeway to Venetian Causeway	29.08×10^7	10.45	6	17.0×10^8	22.82×10^8
4	Venetian Causeway to MacArthur Causeway	4.27×10^7	1.54	8	3.42×10^8	4.2×10^8
5	MacArthur Causeway to Rickenbacker Causeway	18.40×10^7	6.60	9	16.55×10^8	19.98×10^8
a-i	Certain minor bays, inlets, etc.	3.6×10^7	1.29	7.5	2.73×10^8	3.36×10^8
TOTAL		70.4×10^7	25.30	6.9	48.33×10^8	61.45×10^8

The Bay is crossed by five causeways and bridges. From north to south they are: Broad Causeway; 79th Street Causeway; Venetian Causeway; MacArthur Causeway; and Rickenbacker Causeway, which conveniently divide Biscayne Bay into six areas, as shown in Table I.

According to our computations the mean tidal range over the whole bay is roughly 1.9 feet. This has given us the opportunity to estimate the volume of water in the bay during slack high tide. However, before doing this, the time differences In the occurrence of high tide in the bay area must be considered. According to the Current Tables, Atlantic Coast, North America, 1954, published by the U. S. Coast and Geodetic Survey, the current direction changes occur in Baker's Haulover Cut 15 minutes earlier than between the jetties of Government Cut, and close to the Causeway Terminal Yacht Basin ("Approach Outer Cut") 55 minutes later than between the jetties. According to the Tide Tables, East Coast, North and South America, 1954, published by the same agency, the high and low tides occur 75 minutes later at the east end of the Rickenbacker Causeway and 100 minutes later at Miami City Yacht Basin (at the east end of MacArthur Causeway) than at the ocean pier, off the jetties. According to the 1949 report of the Florida State Board of Health, the tide a Baker's Haulover is 25 minutes later, and at the 79th Street Causeway, 3 hours and 25 minutes (205 minutes) later, than at the ocean pier, off the jetties. A careful study of all available current and tide measurements over Biscayne Bay showed that the effect of the later occurrence of tides is relatively small. Therefore, as the most probable tidal "range" indicating the changes in water volume, 1.85 instead of 1.9 was selected , and the volume of Biscayne Bay during a mean high tide was thus estimated to be 61.45×10^8 ft^3. It can be estimated that during each flood tide, about 1.3×10^9 ft^3 of water are brought into the Bay, increasing water volume of the Bay by some 27 per cent.

Four comparatively small fresh water rivers and canals drain their waters into the Bay. These are, starting from the north: Arch Canal, Biscayne Canal, Little River Canal, and Miami River. All have their source in the Everglades area, and come down to the Bay laden with organic matter, the color of their waters being very dark. The discharge of Miami River is greater than those of the other three combined. Miami River is essentially an open sewer. A narrow channel, part of the intra-coastal waterway, connects the northern apex of the Bay with the southerly areas.

The water flow of Miami River, on a monthly basis, varies between 1 ft^3/sec. (June 1945) and 2293 ft^3/sec (September 1947) according to Surface Water Supply of the United States, published by the U.S. Department of the Interior. Since these values are measured at Hialeah, Florida and since it is estimated that flow at the mouth of Miami River is approximately 20 per cent larger, a maximum monthly discharge must be about 2750 ft^3/sec. This corresponds to an amount of 1.23×10^8 ft^3 during one whole tidal cycle, or 1/10 of the amount of sea water brought into the Bay by the flood currents during the same period. The mean discharge from the Miami River at Hialeah is only 605 ft^3/sec, and thus about 725 ft^3/sec at the mouth, corresponding to 3.25×10^7 ft^3/sec during a tidal cycle. Thus, on an average, the discharge from the rivers and canals draining into the Bay is less than 5 per cent of the flood transport.

The northern apex of Biscayne Bay is open to the ocean at Baker's Haulover. The Bay is also open to the ocean at Government Cut, the main navigation channel, which is approximately one-quarter of a mile wide and in which the depth of the artificial channel is about 30 feet at low tide. The southernmost part of the Bay area in question, between MacArthur and Rickenbacker Causeways, is open to the ocean at Norris Cut. The same area is connected through cuts (bridges) of the Rickenbacker Causeway with the southernmost, almost non-polluted part of the Bay, which is open to the ocean at Bear Cut and south of Key Biscayne.

The dimensions of the above cuts, according to our soundings made in June and July, 1954, are shown in Table II.

C. Hydrographic Stations

The 136 main stations of this study and station numbers used in the 1949 report of the Florida State Board of Health (in parentheses) are listed below. At these stations samples were taken for later salinity determinations and the temperatures were recorded. The per cent saturation of dissolved oxygen was determined from other samples collected for dissolved oxygen, and from temperature and chloride content. For current and salinity studies in the cuts and other critical points, 19 additional stations were used.

Table II. Dimensions of the Most Important Cuts of Biscayne Bay.

Name of Cut	Width (ft.)	Mean Area of Vertical Cross-Section (ft^2)
Baker's Haulover Cut	420	8,350
Government Cut	900	16,600
Norris Cut	1,650	18,900
Bear Cut	2,280	27,100
Cut under the main bridge, Rickenbacker Causeway	3,360	30,900
Cut under the western bridge, Rickenbacker Causeway	600	4,400

Main Stations of the Biscayne Bay Pollution Study
(* Biological and Bacteriological Stations)

I. Cross sections from West to East.

Arch Creek to Baker's Haulover Cut:
101 (76), 102 (76A), 103 (78), 104 (79)

79th Street Causeway:
201 (39F), 202 (39), 203 (40), 204 (40W), 205 (41E), 206 (41).

Buena Vista to Sunset Islands:
301 (35), 302 (35A), 303, 304*, 305, 306 (46).

North of the Venetian Islands:
401* (31), 402 (31A), 4031 404, 405, 406* (48).

Flagler Monument Line:
501 (30), 502. 503, 504, 505, 506 (51)

MacArthur Causeway (Main Ship Channel):
601 (17), 602 (16), 603 (18). 604 (19), 605* (20), 606 (21), 607 (22), 608* (23), 609 (24), 610* (25), 611 (26), 612 (27), 61.3 (27D), 614.

Miami River to Norris Cut:
701 (10), 702 (32), 703* (12), 704, 705 (13), 706 (54)j 707 (55), 708* (56), 7091 710*, 711, 712, 713.

North Side of Rickenbacker Causeway:
801* (66), 802 (65), 803 (64). 804 (63).

Fair Isle to Virginia Keys
901 (91), 902, 903, 904, 905 (95), 906.

Dinner Key to Bear Cut:
1001 (93), 1002, 1003, 1004, 1005, 1006, 1007, 1008, 1009

Cross sections from North to South:

Western Line:
101 (76), 2 (75) 3 (74), 4 (73), 203 (40), 202 (39), 6 (38), 7 (37), 8* (36), 301 (35), 10 (34), 11 (33), 12 (32), 401* (31), 501 (30), 55 (29), 602 (16), 16* (15), 17 (14), 705 (13), 704 20* (72), 21 (71), 22 (70), 23 (69), 24 (68), 25 (67), 801* (66), 901 (91), 28* (92), 1001 (93), 30, 31.

Intracoastal Waterway:

Northern Part:
41 (77), 102 (76A), 43 (75A), 44 (75A), 45 (73A), 203 (40), 47 (38), 48 (37A), 49 (36A), 305 (35A), 51 (34A), 52 (32A), 402 (31A), 501 (30), 55 (29), 603 (18).

Southern Part:

61, 62, 804 (63), 905 (95), 65 (94), 66*, 1004.

Dodge Islands to Rickenbacker Causeway:
708 (56), 72 (57), 73 (58), 74 (59), 75 (60), 76 (61), 77 (62).

Eastern Line:
103 (78), 82 (80), 83 (81), 84 (83), 206 (41)s 86 (42), 87 (43), 88* (44), 89 (45), 306 (46), 91 (47),' 406* (48), 93 (49), 94, 95 (50), 506 (51), 97 (52), 98 (53), 99, 609 (24), 711.

Beach Line:
B1(27G), B2 (27F), B3 (27A), B4 (27B), B5 (27C), 613 (27D), B7, B8, B9, B10, B11.

All hydrographic samples except those in the depth experiment in the Main Ship Channel were actually surface samples taken at a depth of 18" below the surface*

D. Overall Hydrographic Study

As a first step of the hydrographic field work all the 136 stations were occupied once and temperatures, salinities, and oxygens were determined accompanied the notations on tidal and weather conditions. This was done in part to become acquainted with the variations in hydrographic conditions in the bay and partly to obtain data for a study of season-to-season changes in the conditions. (The hydrographic work sheet used is included.)

E. General Tidal Conditions in Biscayne Bay

In the overall hydrographic study the significance of the tidal changes was clearly indicated by all the data, and, it was felt that all hydrographic, pertinent biological, all bacteriological and chemical data should be corrected for tidal changes since only in this way could clear-cut correlations be shown between the different hydrographic factors and other data, Therefore, as the most important part of the hydrographic field studies, stations were occupied during a period of 12 hours, roughly, to cover one tidal cycle. According to the records of the tide gauge located in Miami off the jetties of Government Cut

$$F = \frac{K_1 + O_1}{M_2 + S_2} = 0.17$$

where M_2 and S_2 are the amplitudes of the two most important semidiurnal tidal waves and, similarly, K_1 and O_1 are the amplitudes of the most important diurnal waves. It is worthwhile mentioning that the F, has the following values at some stations relatively close to Miami:

Location	F Value				
Mayport, Florida	0.18				
Daytona Beach, Florida	0.25				
Cat Cay, B. W. I.	0.05				
Nassau, B. W. I.	0.34	>	0.25 but	<	1.50
Key West, Florida	0.78	>	0.25 but	<	1.50
Havana, Cuba	1.15	>	0.25 but	<	1.50
Everglades, Florida	o.56	>	0.25 but	<	1.50

If the ration, F, is between 0.00 and 0.25, the tides are considered purely semidiurnal; if F is between 0.25 and 1.50, the tides are considered mixed but mainly semidiurnal. Thus, in the area studied, the tides must be almost purely semidiurnal. This justifies the decision to cover only a period of 12 hours.

Biscayne Bay Pollution Study: hydrographic station

Year: 195 ____ Month: ________Day: ________ Time: ____:_____

Station: __________Depth: ___________ft. Cross section:_____(_____)

Tidal current conditions between the jetties at Miami Harbor Entrance according to the Current Tables:

Slack Flood begins	Maximum Flood	Slack Ebb begins	Maximum Ebb
	__________kn.		__________kn.
at ____:_____	at ____:_____	at ____:_____	at____:_____

Current according to visual observation: ____

____

Measured current: Direction ____

Speed ____ kn.

Remarks on the measured current ____

____

Weather: _____Cloudiness: ______/10 .

Wind: _______________Sea: _________.

Depth	Temperature		Salinity		Oxygen	
	No.	°C	No.	°C	No.	°C
Surface: ______ft.						
Interm.: ______ft.						
Bottom: ______ft.						

Color of the sea____________________.

Other visual remarks ____.

____.

(If necessary draw a sketch on the backside of this sheet.)

Remarks concerning the occupation of the biological stations: ____________________________.

____.

Hydrographer on board:___________________.

One principal difficulty is the fact that winds, and to a lesser extent, air pressure changes, will alter hydrographic conditions in Biscayne Bay. For practical reasons - the boat used for these studies was an open inboard workboat - field trips were not made in rough weather, thus errors introduced by winds and changes in the air pressure were, we believe, mainly eliminated. This is indirectly shown by the fact that in most cases the tidal cycle data on salinity, oxygen and currents were reversible.

The mean range of the order of magnitudes of the tides in this area is

$$2 \times M_2 = 2 \times 1.20 \text{ ft.} = 2.40 \text{ ft } 73 \text{ cm.}$$

The maximum range associated with the spring tides is

$$2(M_2 + 52) - 2(1.20 + 0.24) \text{ ft.} = 2.88 \text{ ft.} = 88 \text{ cm.}$$

The minimum range, associated with the neap tides is

$$2(M_2 - S_2) = 2(1.20 - 0.24) \text{ ft.} = 1.92 \text{ ft.} - 59 \text{ cm.}$$

This clearly shows that another error is introduced, since for practical reasons it obviously was impossible to occupy all the 12-hour stations during the same conditions. However, since M_2 in this case is rather large relative to S_2, this error does not affect the final results too seriously.

F. Depth Study in the Main Ship Channel

As shown in Table I, the bay is quite shallow over most of its areas and averages 5 to 7 feet (mean sea level) over the northern and central areas, with many areas less than three feet. The southern portion is slightly deeper, averaging about 10 feet (msl) The mean depth of Biscayne Bay north of Rickenbacker Causeway during mean low tide is 6.9 feet, and during mean high tide, approximately 8.8 feet. Thus, it is evident that the bay cannot be an estuary of a two-layer system, generally. This fact made it possible to concentrate mainly on the surface layers. Nev ertheless, in order to study the main inlet of Biscayne Bay, the Main Ship Channel as a possible estuary of a two- layer system, the following stations occupied August 25, 1954, during twelve hours to obtain salinity, dissolved oxygen, and temperature data from both the surface and the bottom: 608, 609, 610 and 611, A first interpretation of the data is given in Tables III and IV, which follow.

A graphical example of the preceding data appears in Figure 1 for Station 608 (between Causeway Terminal Yacht Basin and Dodge Islands). As shown, the measured tidal currents follow the predicted currents very closely. In Figures 1-4 the notation "Max. Flood" refers to the predicted tides off the jetties of Government Cut. The times corresponding to the notations "Slack", "Max, Ebb", and "Slack" are obtained simply by dividing the entire tidal cycle into four equal intervals.) The relationship between the currents and salinity is evident. The salinity of surface samples is distinctly lower than the salinity of bottom water during ebb and also during the first part of flood, i.e., the two-layer character is apparent, During the latter part of the flood however, there are no differences between the surface and bottom, neither in salinity nor in dissolved oxygen. In the more complicated pattern of oxygen, during the latter part of ebb, the surface waters are so heavily mixed with the polluted waters that the oxygen content is higher at bottom than at the surface. (See Figure 1.)

Table III. Salinities in the Main Ship Channel at the Surface and at the Bottom During one Tidal Cycle 25 August 1954 (in parts per thousand)

	Mean Salinity S	Maximum Salinity S_{max}	Minima Salinity S_{min}	Absolute Salinity Range S_{max} - S_{min}	Relative Salinity Range 1/s ($S_{max} - S_{min}$)
608 a	32.3	36.4	28.2	8.2	0.25
608 b	32.6	36.2	29.0	7.9	0.22
609 a	32.3	36.0	28.6	7.4	0.23
609 b	32.8	35.9	20.7	7.2	0.22
610 a	32.9	35.3	30.5	4.8	0.15
610 b	33.8	35.0	32.6	2.4	0.07
611 a	33.7	35.4	32-0	3.4	0.10
611 b	33.9	35.6	32.2	3.4	0.10

Table IV. Dissolved Oxygen In the Main Ship Channel at the Surface and at the Bottom During one Tidal cycle 25 August 1954 (in per cent Saturation)

Station	Mean oxygen	Maximum oxygen	Minimum Oxygen	Absolute Oxygen Range
608 a	92.1	100.0	79.5	20.5
608 b	92.9	100.0	85.0	15.0
609 a	97.7	116.0	80.8	35.2
609 b	94.6	111.0	80.8	30.2
610 s	92.7	105.0	82.5	22.5
610 b	90.8	98.5	81.5	17.0
611 s	90.8	99.7	80.2	19.5
611 b	91.5	100.0	80.5	19.5

s - surface; b - bottom

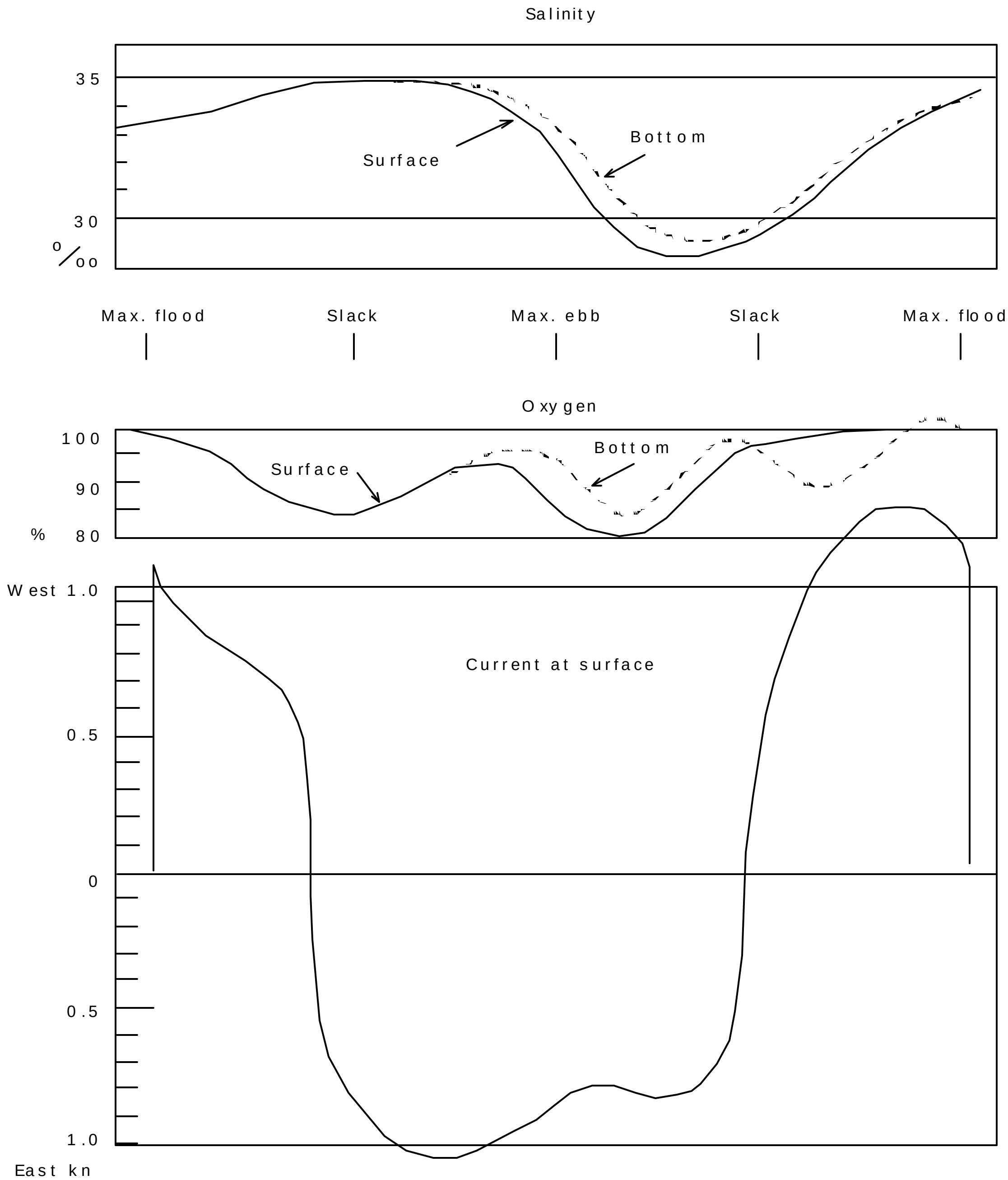


Figure 1. Station 608; Aug. 25, 1954.

G. Tidal Changes of Surface Salinity and Dissolved Oxygen

There are several reasons for paying special attention to the tidal changes of salinity and dissolved oxygen in Biscayne Bay. The tidal changes are so significant that individual observations seem to have practically no value. The ranges salinity and of dissolved oxygen, in addition to the mean values, give a relatively good picture of conditions. In order to relate any individual observation, if necessary, to any selected tidal phase, the tidal changes of salinity and dissolved oxygen must be known. Obviously, the relationship between salinity and dissolved oxygen changes depends basically on the tidal changes.

The following 57 stations were occupied during twelve hours for the study of tidal effects on salinity and dissolved oxygen:

December 23, 1953:
505, 506, 93, 94, 95, 97, 98, 99

December 30, 1953:
607, 608, 609, 610, 611, 708, 709, 710, 711.

January 28, 1954:
702, 703, 706, 707, 17, 20, 21, 22.

January 30, 1954:
501, 502, 602, 603, 604, 605, 16, 55.

February 1, 1954:
301, 401, 403, 404, 10, 11, 12, 51, 52.

September 1, 1954:
801, 804, 905, 24, 62, 73, 75, 76.

September 10, 1954:
303, 304, 305, 406, 8, 49, 91.

A first interpretation of the data is given in Tables V and VI, which follow.

Another graphical example of the preceding data appears in Figure 2 which shows salinity and dissolved oxygen changes at Stations 710 and 711 between Fisher Island and Dodge Islands, 711 being the more easterly station, The large fluctuations in the salinity and dissolved oxygen are noted immediately. Two different water masses can be recognized, one with a high salinity and a rather high oxygen content, the other with much lower salinity and relatively intense pollution. It is also clear that the highly saline water comes from the west, i.e., from the area between Dodge Island and Rickenbacker Causeway, flowing probably relatively directly through Norris Cut around Fisher Island. The decreasing oxygen content of this water indicates that the water is being mixed with the more heavily polluted water from the Main Ship Channel. The less saline waters in this area are those ebbing from the most heavily polluted area, flowing probably directly from west to east.

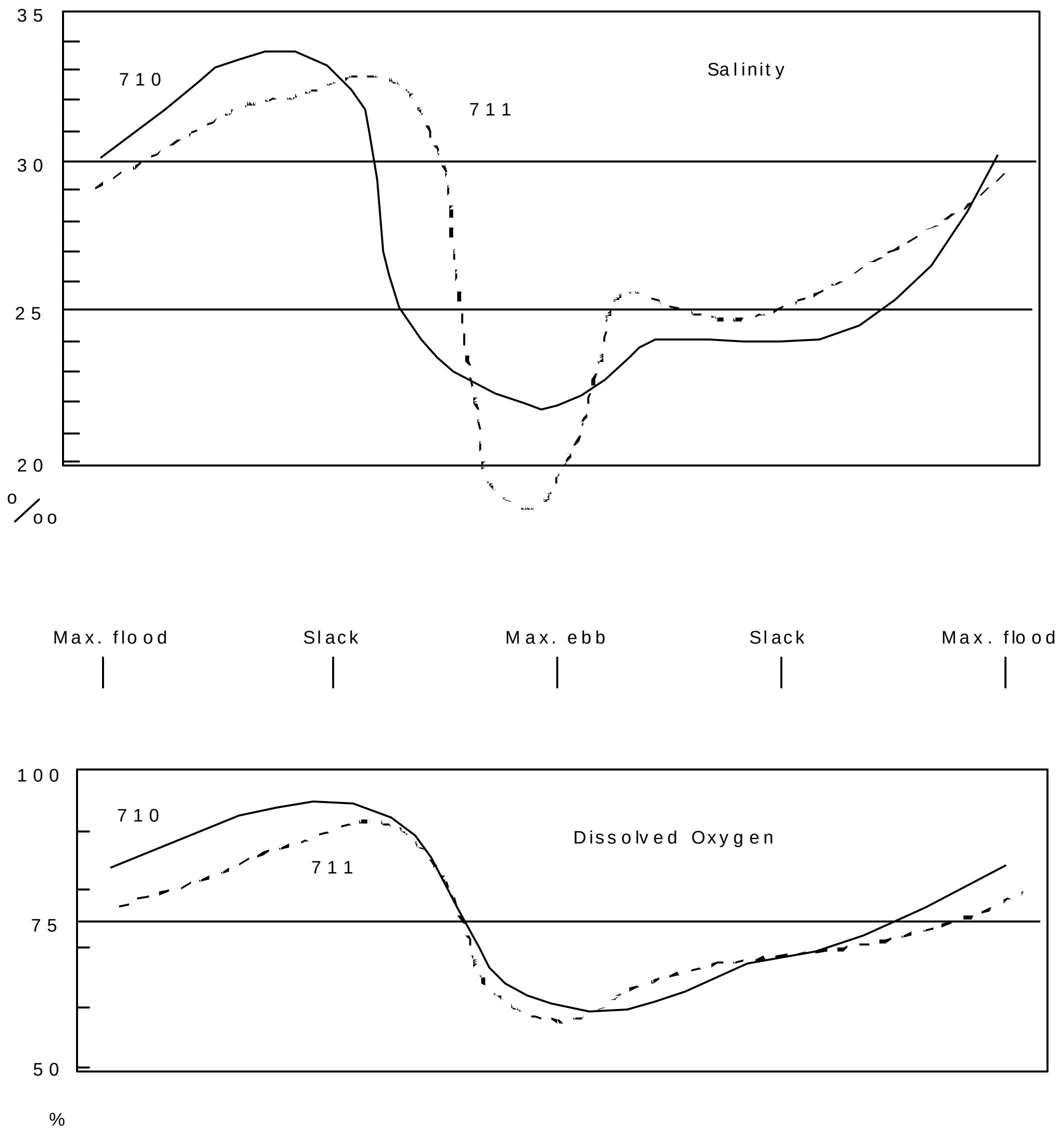


Figure 2. Stations 710 and 711; Dec. 30, 1953.

Table V. Surface Salinities During One Tidal Cycle in Biscayne Bay (in parts/thousand)

	Mean Salinity S	Maximum Salinity S_{max}	Minima Salinity S_{min}	Absolute Salinity Range S_{max} - S_{min}	Relative Salinity Range 1/s (S_{max} – S_{min})
Dec. 23					
505	29.6	31.9	27.3	4.6	0.16
506	31.2	35.0	27.4	7.6	0.24
93	29.5	34.2	24.8	9.4	0.32
94	31.0	35.6	26.4	9.2	0.30
95	30.9	34.9	26.9	8.0	0.26
97	31.5	35.9	27.1	8.8	0.28
98	32.0	36.4	27.6	8.8	0.28
99	32.3	35.9	28.7	7.2	0.22
Dec. 30					
607	24.1	29.2	13.0	10.2	0.42
608	25.7	32.1	19.3	12.8	0.50
609	27.9	34.4	21.4	23.0	0.47
610	28.6	32.8	24.4	8.4	0.29
611	32.6	36.1	29.1	7.0	0.21
708	22.8	28.4	17.2	11.2	0.49
709	24.6	31.0	18.2	12.8	0.52
710	26.7	34.2	19.2	15.0	0.56
711	27.7	33.8	21.6	12.2	0.44
1954					
Jan. 28					
702	3.4	4.6	2.2	2.4	0.71
703	5.5	7.7	3.3	4.4	0.80
706	28.0	34.2	21.8	12.4	0.44
707	27.0	33.4	20.6	12.8	0.47
17	29.2	31.7	26.7	15.0	0.51
20	23.5	28.1	18.9	9.2	0.09
21	26.3	28.1	24.5	3.6	0.14
22	27.5	30.9	24.1	6.8	0.25
Jan. 30					
501	25.5	29.7	21.3	8.4	0.33
502	27.6	30.8	24.4	6.4	0.23
602	22.3	24.5	20.1	4.4	0.20
603	25.1	29.4	20.8	8.6	0.34
604	24.7	29.8	19.6	10.2	0.41
605	25.0	28.3	21.7	6.6	0.29
16	21.0	24.3	17.7	6.6	0.31
55	24.6	30.2	19.0	11.2	0.46

Table V. Surface Salinities During One Tidal Cycle in Biscayne Bay (in parts/thousand) (cont.)

	Mean Salinity S	Maximum Salinity S_{max}	Minima Salinity S_{min}	Absolute Salinity Range S_{max} - S_{min}	Relative Salinity Range 1/s (S_{max} – S_{min})
1954					
Feb. 1					
301	28.1	28.4	27.9	0.5	0.02
401	29.9	32.1	27.7	4.4	0.15
403	29.4	29.8	29.0	0.6	0.03
404	29.3	29.7	28.9	0.8	0.03
10	28.6	29.1	28.1	1.0	0.04
11	28.6	29.1	28.1	1.0	0.04
12	29.3	30.3	28.3	2.0	0.07
51	28.2	28.5	27.9	0.6	0.02
52	29.2	31.4	27.0	4.4	0.15
Sept. 1					
801	31.2	32.4	30.0	2.4	0.08
804	32.7	33.2	32.3	0.9	0.03
905	32.7	33.2	31.5	1.7	0.05
24	30.2	33.7	26.7	7.0	0.23
62	31.7	33.3	30.1	3.2	0.10
73	32.8	33.2	32.4	0.8	0.02
75	32.7	33.3	31.9	1.4	0.04
76	32.9	33.2	32.3	0.9	0.03
Sept. 10					
308	29.8	30.7	28.6	2.1	0.07
304	29.8	30.9	28.7	2.2	0.07
305	29.9	31.1	29.1	2.0	0.07
406	33.5	33.4	29.4	4.2	0.13
8	30.0	30.7	29.3	1.4	0.05
49	29.6	30.2	28.9	1.3	0.04
91	30.5	32.2	28.8	3.4	0.11

Table VI. Surface Oxygen During One Tidal Cycle in Biscayne Bay (in per cent saturation).

Station	Mean Oxygen	Maximum Oxygen	Minimum Oxygen	Absolute Oxygen Range
1953				
Dec. 23				
505	91.1	95.0	82.0	13.0
506	90.5	96.2	79.0	17.2
93	90.4	97.4	80.7	16.7
94	90.5	96.4	82.0	14.4
95	90.0	94.0	79.0	15.0
97	90.6	95.5	78.0	17.5
98	90.4	97.0	75.2	21.8
99	93.1	102.3	81.5	20.8
Dec. 30				
608	76.6	92.0	53.0	33.0
609	78.9	92.0	63.0	29.0
610	77.6	90.0	70.0	20.0
611	86.1	92.0	76.0	16.0
708	71.7	90.5	56.8	33.7
709	72;3	95.5	60.0	35.5
710	77.9	94.5	59.5	35.0
711	75.6	91.5	58.5	33.0
1954				
Jan. 28				
702	6.6	12.0	2.0	10.0
703	15.4	30.4	5.3	25.1
706	73.6	93.0	50.0	43.0
707	78.1	92.7	53.2	39.5
17	78.6	90.0	71.3	18.7
20	63.5	74.4	54.0	20.4
21	66.8	73.2	60.4	12.8
22	73.0	82.0	61.3	20.7
Jan. 30				
501	71.1	76.6	62.3	13.7
502	76.2	83.0	69.0	14.0
602	58.4	63.9	48.5	15.4
603	70.1	79.3	60.5	18.8
604	69.0	82.2	54.0	28.2
605	70.8	83.3	64.0	19.3
16	56.5	64.0	45.0	19.0
55	67.9	79.4	59.0	20.4

Table VI. Surface Oxygen During One Tidal Cycle in Biscayne Bay (in per cent saturation) (cont.).

Station	Mean Oxygen	Maximum Oxygen	Minimum Oxygen	Absolute Oxygen Range
Feb. 1				
301	64.9	75.0	31.5	23.5
401	75.2	83.0	47.0	36.0
403	79.5	83.5	74.5	90.0
404	80.5	85.7	74.0	31.7
10	71.5	91.0	51.0	40.0
11	60.9	79.9	60.3	19.6
12	70.4	96.5	60.0	36.5
51	75.8	84.5	70.5	14.0
52	78.2	82.5	73.3	9.2
Sept. 1				
801	60.2	78.0	40.7	37.3
804	75.2	79.9	70.1	9.8
905	78.5	83.0	73.0	10.0
24	63.0	70.5	56.0	14.5
62	72.8	78.8	63.0	15.8
73	73.7	82.0	66.7	15.3
75	76.2	81.5	71.8	9.7
76	72.5	83.8	56.5	27.3
Sept. 10				
303	96.4	119.9	77.3	42.6
304	87.9	97.0	77.7	19.3
305	82.0	97.5	70.3	27.2
406	86.2	95.8	79.3	16.5
8	86.0	110.4	56.4	54.0
49	88.7	122.4	59.8	62.6
91	84.3	93.0	76.8	16.2

H. The Per Cent of Saturation of Oxygen

Determinations for dissolved oxygen wore made by the sodium azide modification the Winkler method. At first, chloride determinations were made by titrations with silver nitrate; later. hydrometers were used, since by this simpler method the necessary degree of accuracy was obtained. The per cent saturation of dissolved oxygen was calculated from samples collected for dissolved oxygen content, temperature, and chloride content. Since this test measures the depletion of dissolved oxygen by the organic matter present, such as sewage or industrial wastes, it is most interesting to compare the 1953-1954 results with those obtained in 1949 and 1941. These results are shown in Table VII. It can be seen immediately that, on an average, the per cent saturation of oxygen as determined by identical methods is higher during 1954 than during 1949. This surprising result must be due to the fact that the precipitation for 1953 in the drainage area in question was almost 50 per cent higher than that for 1949. The diluting effect of the plentiful discharge is obvious. One can assume that following a dryer period the pollution of Biscayne Bay would have been much more serious.

Conversely, it can be seen that, in spite of the diluting effect of the discharge, at 15 stations the per cent saturation of oxygen was lower in 1953-1954 n in 1949. All these stations are located close to the mouth of Miami River, along the Main Ship Channel, along the coast of the city of Miami up to Bay Point, in the area between Miami River and Rickenbacker Causeway, one of the stations being south of the main bridge of the Rickenbacker Causeway. Thus, it is clear even from these data that the degree of pollution was significantly higher in 1953-1954 than in 1949, notwithstanding the temporary plentiful dilution resulting from rains high and discharge (See Table VII).

I. Tidal Changes of Salinity Combined with Measured Currents

The following 61 stations were occupied during twelve hours for the tidal effects on salinity and to measure the currents:

June 17, 1954:
703. (Mouth of Miami River)
704. (Off the mouth of Miami River)
603, 604, 706, 706, 16, 17, 20.

July 2, 1954:
801. (Western bridge of Rickenbacker Causeway)
804. (Main bridge of Rickenbacker Causeway)
802, 212, 222, 242, 61.

July 9, 1954:
501, Western bridge of Venetian Causeway)
55. (Western bridge of MacArthur Causeway)
401, 402, 403, 51, 52.

July 26, 1954:
103. (Baker's Haulover)
102, 41, 43, 441, 82.

July 21, 1954:
804 W, 804, 804 E. (Main bridge of Rickenbacker Causeway)
1008 W, 1008, 1008 E. (Bear Cut)

Table VII. Per Cent Saturation of Oxygen at Similar Stations for the Years 1941, 1949 and 1953-54

Station	Station	Dissolved oxygen (percent saturation)			
19541949	1941	1949	1953-54		
301	35	74	74.7	64.9	-9.8
401	31	81	65.6	75.2	+9.6
406	48	115	75.8	86.2	+10.4
501	30	82	71.1	71.1	0
50651	107	74.2	90.5	+16.3	
602	16	85	21.4	58.4	+37.0
603	18	102	67.5	70.1	+2.6
604	19	99	71.6	69.0	-2.6
60520	105	72.4	70.8	-1.6	
607	22	104	75.8	77.8	+2.0
60823	104	76.8	76.6	-0.2	
609	24	104	73.5	78.9	+5.4
610	25	115	71.9	77.6	+5.7
611	26	110	67.3	86.1	+8.8
702	11	33	22.8	10.0	-12.8
703	12	67	38.8	15.4	-23.4
706	54	94	59.0	73.6	+14.6
707	55	100	65.5	78.1	+12.6
708	56	102	71.2	71.7	+ 0.5
801	66	94	67.6	60.2	- 7.4
804	63	105	74.2	75.2	+ 1.0
90595	-	87.2	78.5	- 8.7	
8	36	80	75.5	86.0	10.5
10	34	71	68.3	71.5	+3.2
11	33	75	44.9	66.9	+22.0
12	32	74	71.6	70.4	- 1.2
16	15	91	64.7	67.9	+ 3.2
17	14	91	67.1	78.6	+11.5
20	72	79	62.6	63.5	+0.9
21	71	84	70.2	66.8	-3.4
22	70	85	72.0	73.0	+1.0
24	68	97	75.7	63.0	-12.7
49	36A	-	69.4	88.7	+19.3
51	34A	-	71.0	75.8	+ 4.8
52	32A	-	64.8	78.2	+13.4
55	29	86	63.4	67.9	+ 4.5
73	58	103	76.2	73.7	-2.5
75	60	107	79.8	76.2	- 3.6
76	61	100	76.5	72.5	- 4.0
91	47	110	78.5	84.3	+ 5.8
93	49	124	80.0	90.4	+10.4
95	50	119	75 9	90.0	+14.1
97	52	123	78.6	90.6	+12.0
98	53	113	80.0	90.4	+10.4

August 4, 1954

203 W, 203, 203 E. (Western bridge of 79th Street Causeway)
206 W, 206, 206 E. (Eastern bridge of 79th Street Causeway)

August 11, 1954:

713 N, 713) 713 S. (Norris Cut)
710 N, 710 SE . (Between Fisher Island and Dodge Islands)
608 N, 608. (Between Causeway Terminal Yacht Basin and Dodge Islands)

August 13, 1954:

99. (Close to the bridge between Causeway Terminal Yacht Basin and U.S. Coast Guard Basin)
98 W, 98 E, (Eastern Bridge of the MacArthur Causeway)
611 N, 611, 611 S. (Between the jetties at marker No. 5 in the Government Cut)
93. (Eastern Bascule Bridge of the Venetian Causeway)

August 20, 1954:

501 W, 501, 501 E. (Western bridge of the Venetian Causeway)
55 W, 55, 55 E. (Western end of the MacArthur Causeway)

A first interpretation of the salinity observations at these 61 stations is given in Table VIII, which follows.

To demonstrate for this preliminary report the clear-cut relationship between salinity (the only usable conservative element) and currents) Stations 611 (Government Cut, Figure 3) and 713 (Norris Cut, Figure 4) were selected. (See Figures 3 and 4) Again, it can be seen clearly that the ebbing current is associated with decreasing salinity, and the flooding current with increasing salinity. In Government Cut the currents are swiftest in its deep, middle portion while in Norris Cut, particularly, the flood current is stronger on the deeper northern side.

In Tables III, V and VIII, the absolute salinity range is given in parts per thousand. In order not to emphasize unduly the exceptional extreme values of the salinity, the tidal salinity cycle was analyzed harmonically, provided the range exceeded two parts per thousand. Maximum salinity was then obtained as a sum of the mean salinity and of the amplitudes of the first and second waves. Minimum salinity was similarly obtained as a difference between the mean salinity and the sun of the amplitudes of the first and second waves. Calculated this way, the absolute salinity range is much more reliable than making direct uncritical use of the extreme readings without a proper smoothing procedure. (The absolute oxygen ranges given in Tables IV and VI are read directly from the graphs drawn from the original data).

The regional distribution of the absolute salinity range can be used to define the areas with different intensities of flushing, which are shown in Figures 5 and 6 which follow.

It is worth mentioning that the pattern of the relative salinity range is practically identical with that of the absolute salinity range. The only discrepancy is seen in the mouth of Miami River, where the absolute range decreases while the relative range, for obvious reasons, either remains constant or even increases.

Several features of the water exchange of Biscayne Bay can be recognized in Figures 5 and 6. Maximum flushing is seen at the conjunction of the Intracoastal Waterway with the flood currents flowing into the Bay through Baker's Haulover Cut. A secondary minimal flushing area

Table VIII. Surface Salinities During One Tidal Cycle in Biscayne Bay (in parts/thousand).

	Mean Salinity S	Maximum Salinity S_{max}	Minima Salinity S_{min}	Absolute Salinity Range S_{max} - S_{min}	Relative Salinity Range 1/s (S_{max} – S_{min})
1954					
June 17					
703	8.9	13.3	4.5	8.8	0.99
704	12.4	16.1	8.7	7.4	0.60
603	23.4	30.3	16.5	13.8	0.59
604	23.8	28.3	19.3	9.0	0.38
705	21.6	25.8	17.4	8.4	0.39
706	17.7	24.2	11.2	13.0	0.73
16	23.0	27.7	18.3	9.4	0.41
17	21.9	27.3	16.5	10.8	0.49
20	25.8	30.3	21.3	9.0	0.35
July 2					
801	22.9	24.6	21.2	3.4	0.15
804	30.0	31.4	28.2	3.2	0.17
802	23.9	26.5	21.3	5.2	0.22
21	20.8	27.8	13.8	14.0	0.67
22	23.3	27.3	19.3	8.0	0.34
24	22.6	25.8	19.4	6.4	0.28
61	27.4	29.5	25.3	4.2	0.15
July 9					
501	23.1	26.2	20.0	6.2	0.27
55	22.7	26.7	18.7	8.0	0.35
401	23.1	26.6	19.6	7.0	0.30
402	23.4	24.7	22.1	2.6	0.11
403	25.0	28.5	21.5	7.0	0.28
51	23.4	23.8	23.0	0.8	0.03
52	23.6	24.1	23.1	1.0	0.04
July 26					
103	33.9	39.0?	28.8	10.2	0.30
102	27.6	32.6	22.6	10.0	0.36
41	22.6	31.1	14.1	17.0	0.75
43	24.7	25.8	23.6	2.2	0.09
44	24.6	26.4	22.8	3.6	0.15
82	28.7	33.6	23.8	9.8	0.34

Table VIII. Surface Salinities During One Tidal Cycle in Biscayne Bay (in parts/thousand) (cont.)

	Mean Salinity S	Maximum Salinity S_{max}	Minima Salinity S_{min}	Absolute Salinity Range $S_{max} - S_{min}$	Relative Salinity Range $1/s\ (S_{max} - S_{min})$
1954					
July 21					
804 W	27.6	28.2	27.0	1.2	0.04
804	28.0	29.1	26.9	2.2	0.08
804 E	27.9	28.8	27.0	1.8	0.07
1008 W	31.6	34.7	28.5	6.2	0.20
1008	31.2	33.6	28.8	4.8	0.15
1008 E	32.3	35.0	29.6	5.4	0.17
Aug. 4					
263 W	22.6	26.6	19.0	7.6	0.33
203	23.7	26.5	20.9	5.6	0.24
203 E	23.6	26.0	21.2	4.8	0.20
206 W	26.2	28.1	24.3	3.8	0.15
206	26.7	28.2	25.2	3.o	0.21
206 E	26.9	28.0	25.8	2.2	0.08
Aug. 11					
713 N	32.6	35.7	29.5	6.2	0.19
713	32.9	36.6	29.2	7.4	0.23
713 S	32.5	36.3	28.7	7.6	0.23
710 N	31.4	35.1	27.7	7.4	0.24
710 SE	31.3	34.6	28.0	6.6	0.21
608 N	30.1	35.2	25.0	10.2	0.34
608	30.6	34.5	26.7	7.8	0.26
Aug. 13					
99	31.0	33.7	28.3	5.4	0.17
98 W	30.8	33.6	28.0	5.6	0.18
98 E	30.6	34.1	27.1	7.0	0.23
611 N	31.4	34.3	28.7	5.6	0.18
611	31.2	33.9	28.5	5.4	0.17
611 S	31.5	34.6	28.2	6.4	0.20
93	29.4	30.5	28.3	2.2	0.07
Aug. 20					
501 W	27.1	30.8	23.4	7.4	0.27
501	28.1	30.2	26.0	4.2	0.15
501 E	27.9	30.7	25.1	5.6	0.20
55 W	24.7	31.4	18.0	13.4	0.54
55	27.7	33.5	21.9	11.6	0.42
55 E	27.3	32.0	22.6	9.4	0.04

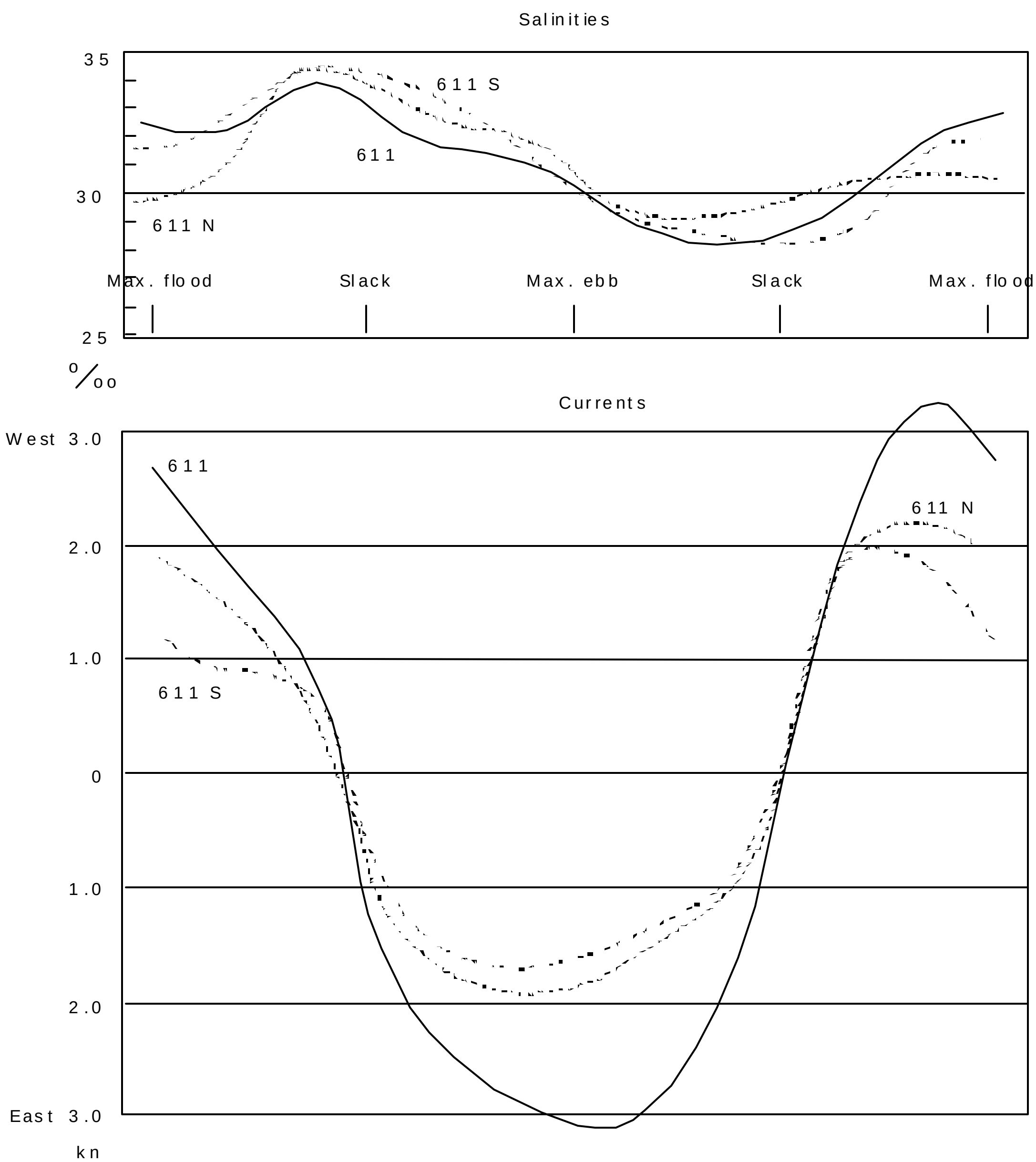


Figure 3. Stations 611 N, 611, 611 S; Aug. 13, 1954.

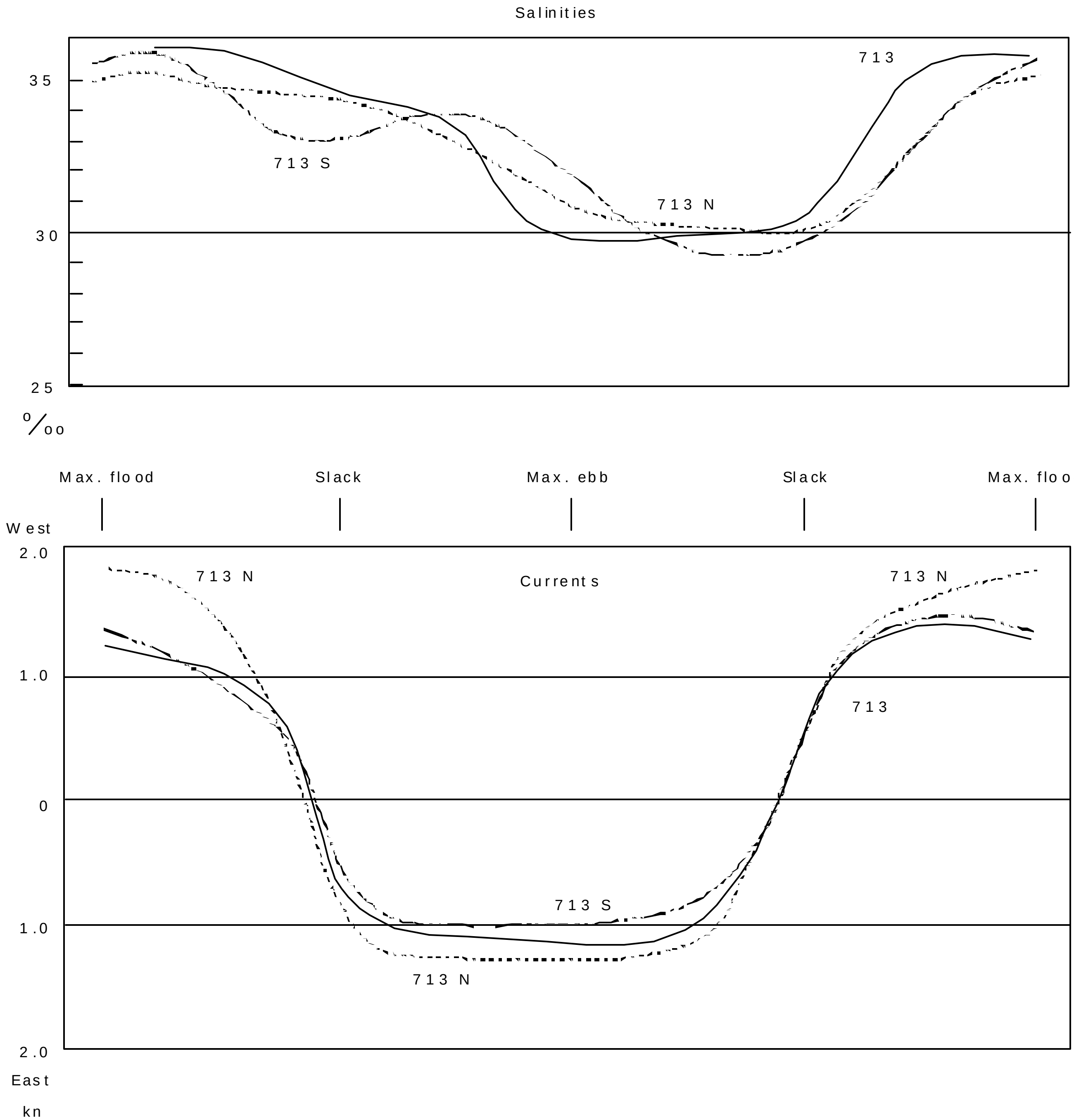


Figure 4. Stations 713 N, 713, 713 S; Aug. 11, 1954.

seems to exist around the Broad Causeway. A less important area with relatively high salinity range is found in the vicinity of the mouth of Little River and 79th Street Causeway. The limited number of stations in this area makes it difficult to describe the true paths of the isolines. A large area with only slight flushing exists between 79th Street Causeway and Venetian Causeway. One may predict that this should show the final effects of pollution most clearly, due to the limited flushings. Another area with maximal flushing lies between Venetian and Rickenbacker Causeways, with the extreme between the mouth of Miami River and Fisher Island. according to the few available data from the area south of the Rickenbacker Causeway, the absolute range of salinity seems to be relatively small.

Particular attention is called to the high salinity range less than half a mile east of Bayfront Park (north of the mouth of Miami River). This clearly indicates that the relatively pure ocean water, coning through Gov ernment Cut (possibly, to a lesser extent, also through Norris Cut) and flowing between Dodge Islands and Fisher Island, penetrates this part of the polluted area twice daily,

The other main features of the water exchange can be seen in Figures 5 and 6. The waters from Little River seems to flow mostly northerly. Also, the flood current between the jetties follows the western coast of Miami Beach. Our experience clearly indicates that by this means a part of the polluted ebbing waters is brought back into the Bay, along the western coast of Miami Beach; later, when the flood is more developed, relatively pure ocean waters are brought along this coast and towards the mouth of Miami River.

J. Season-to-season Changes in the Hydrographic Conditions

Before the entire hydrographic study can be considered as complete, the season-to-season changes in the hydrographic conditions must be examined. Tentative conclusions show clearly that both changes in discharge from the fresh-water rivers, and the varying mixing conditions, due to the winds, affect the general hydrographic pattern in Biscayne Bay. Although not practicable, a really synoptic picture of conditions in the bay could only be obtained if a full series of stations were examined simultaneously through the same tidal cycle. Further, a number of similar synoptic representations would be needed, each referring to different discharge conditions, to different mixing conditions effected mainly by the winds, and even to different periods of the lunar month. Since for practical reasons this is completely impossible, the problem of the changing hydrographic conditions must be approached another way. For this study, besides other data already mentioned, the hydrographic data from the 16 biological, bacteriological and chemical stations is available, since these stations were occupied on an average of more than 6 times during different months, hence during different conditions.

K. Summary of Results

The region under consideration has an area of 25.30 square miles (70.42 X 10^7 square feet), an average depth of 6.9 feet and a volume of 48.33 x 10^8 cubic feet at low tide and 61.45 X 10^8 cubic foot at high tide. The influx of sea water on the rising tide is about 27%, or roughly a quarter of the law tide volume. The mean contribution from fresh-water rivers and canals is less than 5 per cent of this.

The tides are mainly semidiurnal so it is sufficient to study one 12-hour cycle at many selected stations.

The shallower areas of the bay constitute a one-layer system and are adequately represented by surface samples.

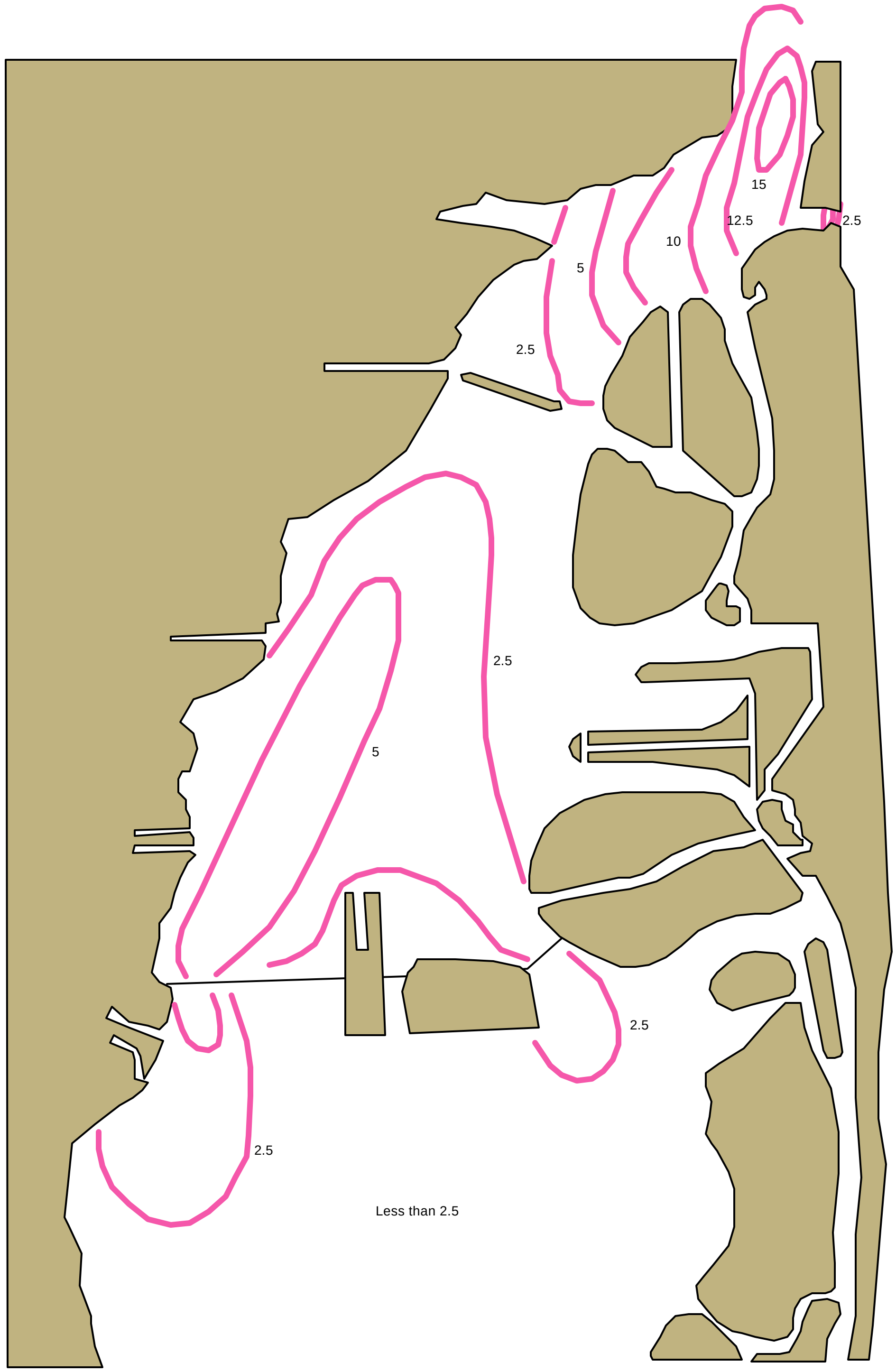


Figure 5. Regional distribution of the absolute range of salinity

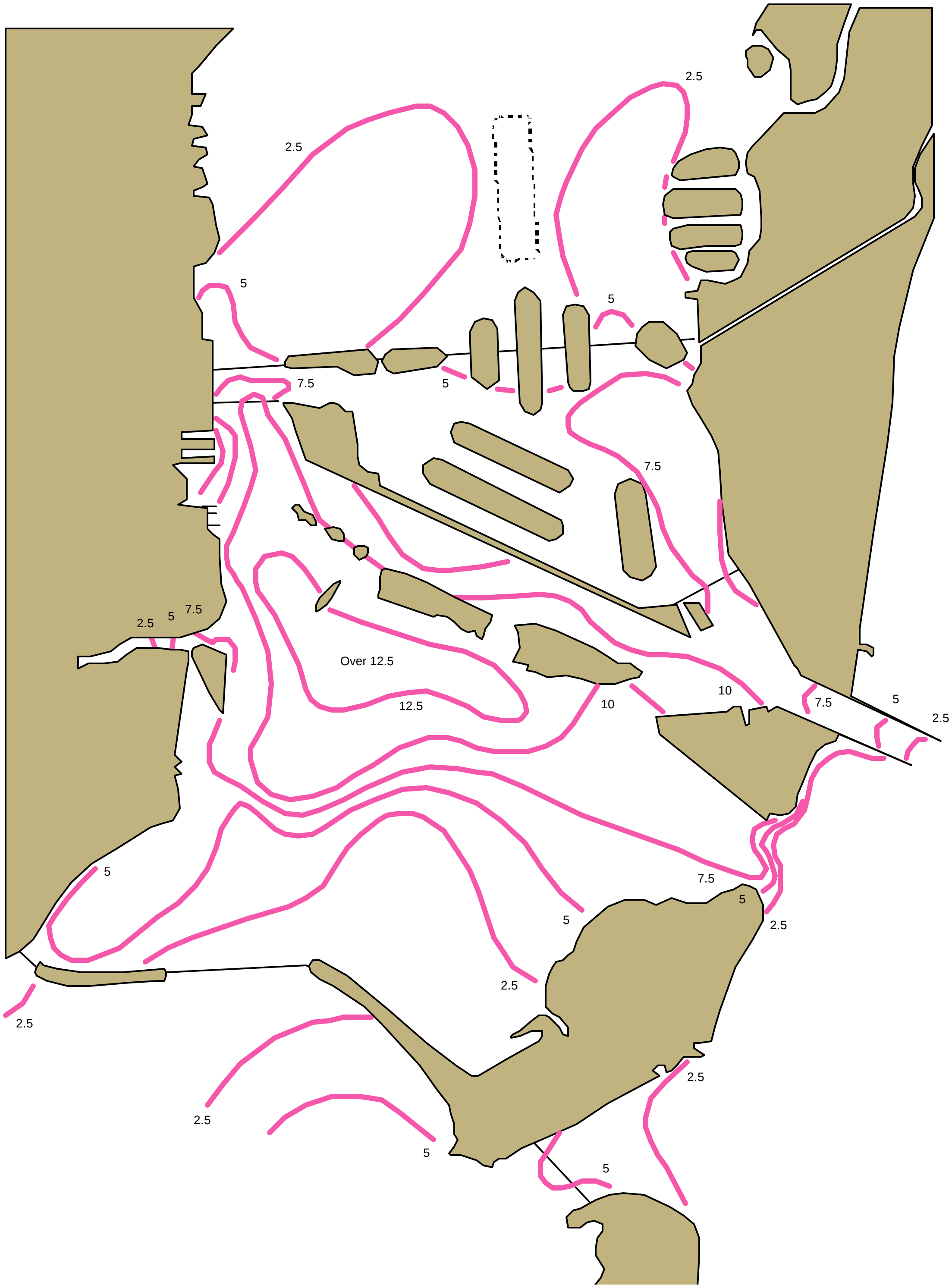


Figure 6. Regional distribution of the absolute range of salinity

The Main Ship Channel is sufficiently stratified to constitute a two-layer system except during the later part of the flood tide, when it is sufficient mixed to constitute a one-layer system.

Salinity changes are so great during a tidal cycle that samples taken at any one time cannot adequately reflect conditions in a given locality. It is essential that a locality be characterized through a synoptic picture of conditions as they vary through an entire tidal cycle.

Comparisons with surveys made in 1941, 1949 and 1953-54 show that pollution, as indicated by oxygen concentration, is greater in the year of the latest survey despite the diluting effects of greater rainfall.

From studies of tidal salinity changes, figures are presented showing the relative extent of tidal flushing in different parts of the area.

II. CHEMICAL STUDIES

J. Kneeland McNulty and Sigmund Miller

A. General

An understanding of the Biscayne Bay area and its water exchange necessarily precedes a report on other parameters studied under this contract. A preliminary hydrographic study covering all stations throughout the bay yielded data on the range of conditions throughout the area. This information was used in the selection of key stations for combined hydrographic-bacteriological-chemical-plankton studies plus) of course, stations for additional biological and physical observations alone. Since 16 stations were found to be a reasonable number from which significant results might be obtained, these were chosen by assent of all persons contributing to this study. All but one, (Sta. 28 at Dinner Key, about 2.1 nautical miles southeasterly from Rickenbacker Causeway) are shown in Figure 7. This figure shows the location of stations where the major effort on chemical studies was made.

Of the many chemical tests that might have been made, phosphorus and nitrogen determinations were chosen because they provide a reliable measure of the nutrient material being supplied to the bay. Evaluation of the precise role of sewage in this nutrient supply will await future determinations when sewage no longer empties into the bay, the difference between future values and those here reported being a measure of nutrients ascribable to sewage alone. In order that this comparison be attainable in the future, and for purposes of present analyses, a relatively complete study of the "components" of phosphorus existing under present conditions was undertaken. These determinations have made it possible to calculate mean phosphorus components for the above stations with respect to (1) phosphate-phosphorus, (2) particulate- phosphorus, (3) dissolved phosphorus, (4) dissolved organic phosphorus, and (5) total phosphorus (sum of dissolved and particulate). Nitrite-nitrogen and nitrate-nitrogen determinations accompany some, but not all, of the above tests for phosphorus components so that mean nitrogen results are not directly comparable with mean phosphorus results but are most useful in conjunction with individual results. Except for phosphate- phosphorus, mean results for other components represent samples through several tidal phases at each station, scattered so as to provide a reasonable range with respect to tidal conditions. Phosphate-phosphorus determinations were made concomitant with all but six bacteriological determinations, and so are me-an data for virtually all significant tidal conditions, a conclusion justified by the many "repeat" experiments which showed good agreement with initial results.

B. Combined Sampling

The immediate goal of all studies dependent on tidal conditions has been an array of hydrographic, bacteriological, chemical and plankton data which are mutually comparable by reason of simultaneous sampling. All chemical (and plankton) data have concomitant hydrographic and bacteriological data (see accompanying work sheet, following Figure 7). Those samples obtainable from a common carboy -full have been so taken, i.e., from the identical water mass used for bacteriological analysis. Those not so obtainable, as for instance dissolved oxygen and plankton, have been taken as nearly at the same time as possible. The hydrographic data so obtained are in addition to detailed tidal-cycle hydrographic studies summarized in the preceding section. Thus, a basis for comparison of the combined samples with the detailed hydrographic samples has been established, and indications as to seasonal hydrographic changes can be provided.

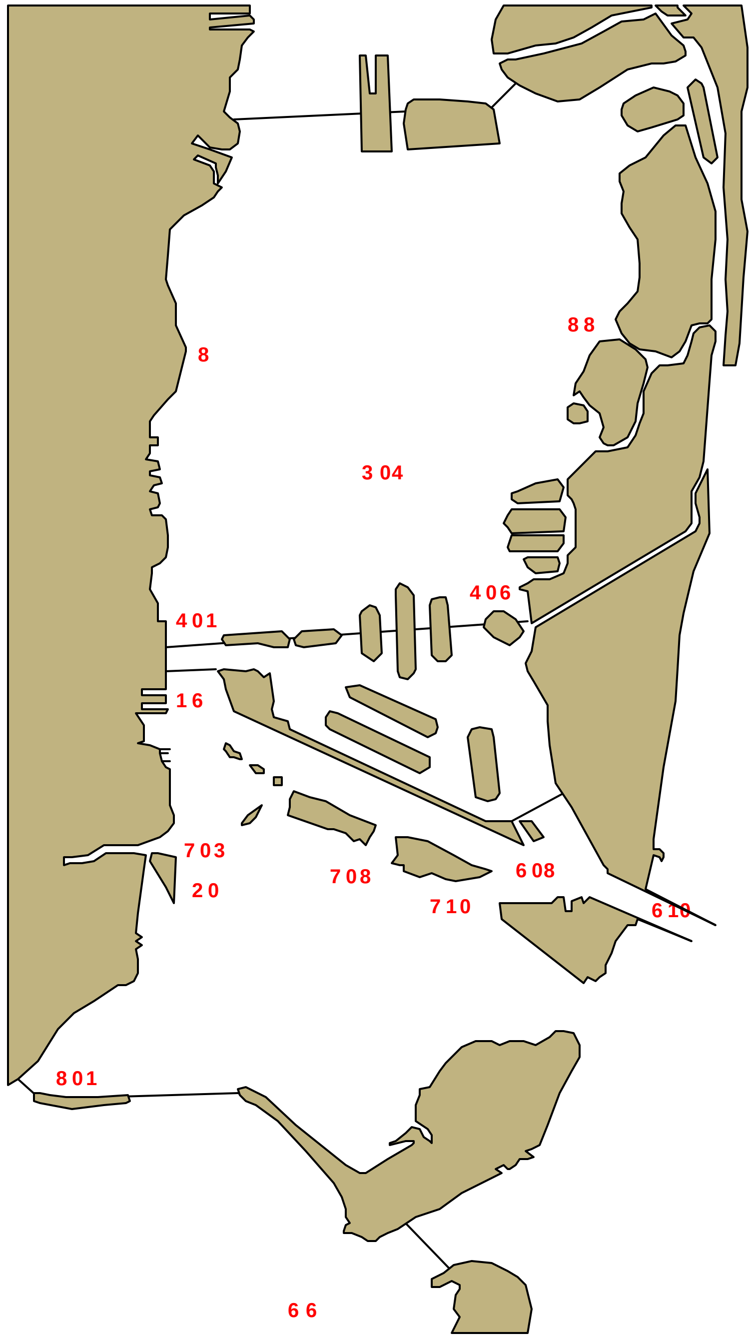


Figure 7. Station locations for combined hydrographic-bacteriolocigal-chemical-plankton sampling and fouling, marine borer and bottom studies. [LAND MASSES IN ORIGINAL IMPOSSIBLE TO SCAN. APPROXIMATE LOCATION OF STATIONS SHOWN IN COMPOSITE CHART PREPARED FROM FIGURES 5 AND 6.]

Due to wide variations in hydrographic-bacteriological-chemical- plankton results according to tidal conditions, field work was planned weeks in advance to ensure that field work be done at a precise time with respect to tidal phases. The inherent weakness in any random "system" of sampling under estuarine conditions should be obvious, particularly from results in this report. As the work progressed it became clear that at least 6, and preferably 12 or more, carefully spaced samples per station per tidal-dependent variable should serve as a basic minimum in an estuary of this type.

C. Materials and Methods

The choice of materials and methods and their application to this problem have been under the supervision of Mr. Miller, whose account occupies the reminder of this section. It should be mentioned here that the numerous "routine" oxygen and salinity determinations involved in this study have all been conducted under Mr. Miller's supervision. Reference to the methods used appears in the preceding section.

Methods

Water samples for chemical determinations were collected in a five gallon carboy at each station. A 250 mL sample was withdrawn from this immediately, and the phosphate-phosphorus concentration determined on board, using the method of Robinson and Thompson (1948). Thirty- centimeter Nessler tubes were used for visual comparison of the samples with standards.

Since the water samples were frequently contaminated with sewage, tannins, etc., it was found to be advantageous to modify the method of visual comparison. In addition to preparing a set of standards for each group of determinations, a Nessler tube was filled to the brim with the stock sodium chloride solution used for the preparation of standards, and a second tube was filled to the brim with water from the station being studied. By arranging the Nessler tubes in the manner shown in Figure 8, it was possible to compensate for the interference caused by discoloration of the water samples.

250 mL samples were also withdrawn immediately from the carboy for nitrate-nitrogen and nitrite-nitrogen analyses. Chloroform was used as a preservative.

The method of Bendschneider and Robinson (1952) was used for determination of nitrite-nitrogen. One mL of 1% sulfanilamide in 1.2N HCl and 1 mL of 0.10% N(1-naphthyl-ethylenediamine dihydrochloride are added to a 50 mL sample and the optical density is compared to that of standards in a Beckman Spectrophotometer using 10 cm absorption cells.

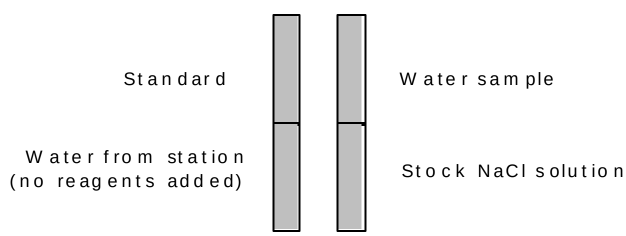


Figure 8. Arrangement of Nessler tubes for visual comparison.

BISCAYNE BAY POLLUTION STUDY Serial No. __________

Combined Hydrographic - Bacteriological - Chemical - Plankton Form

Hydrographic | Tides at jetties | Observed Current _________

Date__________

SF begins__________
Max. Flood_________

Weather & clouds __________/10

Sta.__________

Kn._______________
SE begins__________

Wind_________ Sea___________

Time____to__________

Max. Ebb___________
Kn._______________

Color_______________________

Depth___________ft;

Oxygen No.__________________

Salinity No._________

Temp.________°C

Chlorinity__________ppt

O_2____________________mL/L

Salinity___________ppt

____________________% Sat.

Remarks____

Bacterial MPN No.____________
MPN_______________

BOD No. ______________ & ______________
Initial O_2_________mL/L; final_________mL/L
" " __________%; final____________%

Count___________________________
Ident.___________________________

BOD value_____________________________

Salinity___________ppt

____________________% Sat.

Remarks____

Chemical NO_2-N No.__________ NO_3-N No.__________ Part. N_2 µg-At N_2/L.________
-log T_____________ -log T_____________
µg-A/L____________ µg-A/L____________

PO_4-P µg-A/L___________________ Part-P -logT____________ Diss-P -log T_________
g-A/L___________ µg-A/L______________

Diss. Org. P µg-A/L___________________ Plt. Pig., mL used_________; HU/m^3________
HU/mL_____________: µg Org. C/m^3_______

Additional data and remarks____

Plankton Net Size___________ Vol. P mL__________

Cy'r R'ding $_2$____________

C-B Col. _____________ L/cycle; L strained ___________

Cy'r R'ding $_1$_____________
Cy'r R'ding $_d$ _____________

mL P/10,000 L [UNDECIPHERABLE] ___________ Remarks ___________________

The method of Foyn *(1951)* was used to prepare samples for analysis of nitrate-nitrogen. A 100 mL sample is reduced over 40 g of 10 mesh zinc in 1:20 HCl by beating in a boiling water bath for 1.5 minutes. The sample is then analyzed in the same manner as for nitrite-nitrogen, with the exception that the standards are prepared from sodium nitrate solutions which are reduced in the same manner as the samples.

As soon after collection as possible, a measured volume of sample from the carboy is passed through a Sharpless Super Centrifuge. A volume of *5-7* liters was found to be convenient for this purpose.

The supernatant was analyzed for total dissolved phosphorus according to the method of Hansen and Robinson (1952). From this and the phosphate-phosphorus analysis, the dissolved organic phosphorus concentration was determined by difference.

The particulate matter retained by the Super Centrifuge is washed into a 125 mL Erlenmeyer flask and oxidized by heating with 5 mL portions of nitric acid until the sample is colorless. The perchloric acid method of Hansen and Robinson (1952) is then used to determine the particulate phosphorus concentration.

D. Results

Analyses were made for phosphate-phosphorus particulate-phosphorus, dissolved phosphorus, dissolved organic phosphorus, total phosphorus, nitrite-nitrogen and nitrate-nitrogen, and for dissolved oxygen and salinity. Except for dissolved oxygen and salinity data, which appear in other sections, tabulations of the data are given in Tables IX and X.

Table IX. Mean Part.-P, $P0_4$-P, Diss. Org.-P and Diss.-P for the Stations Shown in Microgram-Atoms Per Liter.

Sta.	Part.-P µg-a/L	No. Obs.	$P0_4$-P µg-a/L	No. Obs.	Org.-P µg-a/L	No. Obs. .	Diss.-P µg-a/L	No. Obs.
66	0.052	3	0.03	4	0.72	3	0.74	3
801	0.031	4	0.37	6	1.47	4	1.83	4
703	0.044	5	1.07	13	1.56	2	2.52	5
20	0.053	2	0.53	10	1.09	5	1.67	3
708	0.051	5	0 23	6	0.75	5	0.99	5
710	0.068	5	0:14	7	0.77	5	0.94	5
16	0.030	4	0.50	11	0.93	4	1.58	4
605	0.033	4	0.41	11	o.63	4	0.90	4
608	0.021	3	0.15	4	0.75	2	1.12	3
610	0.057	4	0.03	3	0.72	3	0.72	4
401	0.027	5	0.62	6	1.49	5	2.11	5
8	0.027	5	1.10	6	1.96	5	2.96	5
304	0.024	4	0.40	a	0.98	4	1.48	4
406	0.053	6	0.16	7	0.77	6	0.92	6
88	0.024	4	0.17	6	0.79	4	0.94	4

Table X. Mean Total P, $N0_2$-N and $N0_3$-N for the Stations Shown in Microgram-Atoms Per Liter.*

Sta.	Total-P µg-a/L	No. Obs.	NO_2-N µg-a/L	No. Obs.	NO_3-N µg-a/L	No. Obs.
66	0.778	3	0.131	1	-	-
801	1.856	4	0.318	2	5.88	1
703	2.562	5	0.410	3	15.70	2
20	1.878	2	0.324	2	12.50	1
708	1.043	5	0.233	2	9.30	2
710	1.010	5	0.114	2	5.09	2
16	1.613	4	0.483	3	14.40	2
605	0.935	4	0.170	2	7.60	1
608	1.138	3	0.271	2	9.51	1
610	0.727	4	0.214	3	8.07	2
401	2.137	5	0.301	3	14.00	2
8	2.987	5	0.279	2	23.00	1
304	1.500	4	0.546	2	-	-
406	0.976	6	0.362	2	8.67	2
88	0.967	4	0.388	2	-	-

*To convert these data from microgram-atoms per liter to parts per million, multiply any phosphorus component by 0.031 and any nitrogen component by 0.014.

These results are most meaningful in combination with hydrographic, bacteriological and other biological data, so a discussion of their significance is deferred to Section V, Discussion and Conclusions.

III. BACTERIOLOGICAL STUDIES

Ernest S. Reynold

A. Introduction

A brief statement of the sewage pollution sources for Biscayne Bay must be made to ensure an understanding of the results of this study. Three main sources of sewage pollution are present: (1) the Miami River, which flows through a considerable portion of the heavily populated part of Miami and into which numerous sewage outfalls empty; (2) Little River, at the north end of Miami, which flows through a much smaller area of Miami; (3) a series of sewage outfalls along the whole Miami waterfront. It should be stated also that although much of the Miami area is not on the sewage system, the material removed from time to time in cleaning the septic tanks is also dumped into the bay on the Miami waterfront. It appears that the outflow from Little River has little effect on the pollution of the central portion of the bay. The deep waterway and Government Cut, paralleling the MacArthur Causeway from the Miami waterfront, passes between Miami Beach and Fisher Island to the oceans and constitutes the main rapid drainage for the sewage pollution and a means of interchange of ocean water and the heavily polluted bay water of the harbor, other portions of the part of the bay under consideration are connected with the ocean principally by Norris Cut, between Fisher Island and Virginia Key, and secondarily and indirectly southward through Rickenbacker Causeway and northward through Venetian Causeway. The bacteriological data related to these conditions and the relative importance of these connections will appear later in this section. Hydrographic studies of the dynamics of these conditions are described tentatively in Section I.

B. Methods

The sixteen stations chosen for the combined bacteriological-hydrographic-chemical-plankton studies are shown in Figure 7, except for one, station 28, located within the marina area off Dinner Key. An important consideration in selecting these stations was to include a range of areas, from those directly influenced by tides and currents from the open ocean, to those in which the effects of these factors on bacterial numbers were largely indirect. It was considered equally important in planning the sampling operations, to have samples taken at the various stations during all important phases of the tidal cycle and at different seasons of the year and to avoid sampling during exceptional weather disturbances. The presence of lactose-broth fermenting coliform bacteria was used as the criterion of sewage pollution. The Standard Methods of the American Public Health Association for sampling and laboratory procedures were used in the determination of the Most Probable Number and the Biochemical Oxygen Demand. .

From various preliminary studies under local conditions of temperature and transportation, as well as from previous studies by other investigators, it was evident that special care in sampling as well as in laboratory procedures would be necessary in order to obtain reliable, comparable results from the various stations in the bay. Hence the following routine was adopted for each MPN sampling. Chemically sterilized, thoroughly rinsed, five gallon carboys were filled by means of a bucket, previously thoroughly rinsed with the water to be sampled. The MPN samples were siphoned immediately from the center of the carboys through a carefully rinsed rubber tube, into the BOD bottles which had been previously sterilized. These were immediately immersed completely in an ice-and-water mixture for fifteen minutes to chill them rapidly to approximately the subsequent storage temperature, but not lower. They were then transferred to and stored in a cold-air box maintained at about 50 °C. The elapsed time in the box from collection to laboratory treatment was from two to three hours.

In the laboratory the system of five replicates for five dilutions with readings of three significant tubes after twenty-four hours in the incubator was used. The usual dilutions were 1.0, 0.1, 1.01, 0.001, and 0.0001 mL with occasional use of 0.00001 or 10.0 mL dilutions when experience indicated these changes. Occasional additional readings of the MPN results were made after 48 hours incubation and confirmatory brilliant-green lactose bile broth tests were made for various representative stations, and whenever confirmation was desired in any doubtful cases. All bacterial numbers used in this report are in terms of the MPN in 100 mL of the sample.

C. The Pollution Effectivity Index (PEI)

It was learned early in this study that certain stations exhibited sudden, abrupt MPN maxima when water masses of high bacterial content were suddenly introduced by tidal action. Frequently, the duration of these maxima was relatively short. Since ecological effects of sewage pollution is the point at issue in this study, it seemed illogical to give such sudden, short-lived peaks of contamination equal mathematical weight with the lower, more persistent contamination values characteristic of any given station. Consequently, the Pollution Effectivity Index (PEI) was developed to emphasize the relative persistence of the bacterial populations which, it was reached, has a more cogent ecological significance.

Graphs of the MPN results on cross section paper were prepared for each station, Figures 9, 11, 12 and 13, laying off on the axis of abscissas the 12.42 solar hours of the tidal cycle, with the beginning of the flood tide (F0) at the axis of coordinates. The most probable numbers of the coliform-type bacteria, in uniform units, give the principal points on the curve. The space below the curve is a measure of the total pollution effectivity at that station during the tidal cycle of twelve lunar hours, since that portion of any line parallel to the X-axis enclosed beneath the curve indicates the length of time the corresponding number of coliform-type organisms were present. Extrapolations of the graphs to the beginning and the and of the tidal periods were made on the basis of the actual observations which form he main part of the graph. This method assumes that the MPN in the extrapolated portions of the curves would be consistent with the adjoining established parts of he curve.

Planimeter determinations of the areas) in square inches, beneath the completed tidal curves were multiplied by the MPN of bacteria represented by the graph paper-unit. Due to the great differences in the MPN maxima at the different stations, it was necessary, in order to use graph paper of convenient size, to have the smallest graph-paper-unit represent variously 2.0, 50, 125, 500, or 2000 MPN of bacteria.

The planimeter determination is made in order to obtain a numerical value which represents the product of the total length of time the coliform bacteria are present during the tidal cycle, times the total number of such bacteria present during the cycle, This gives an integration of time multiplied by bacteria, or in other terms, the relative "bacteria-hours" for the station over the tidal cycle.

Since an MPN of 1 persisting throughout the tidal cycle can be considered 3 minimum of pollution, the figure obtained by the preceding operation can be divided by twelve, which gives what may be considered the absolute PEI for the station under the conditions of the study.

Explanation of the MPN Graphs (Figures 9, 11, 12 and 13)

1. Each graph has the Station Number in the upper right hand margin.

2. Below this number is an indication of the magnification which would be necessary in order to make the graph on the same scale as all of the other graphs in the series. It is also an indication of the MPN represented by the smallest square the graph sheet. On the original graph sheet the smallest square was 1/20 of an inch square. Thus the graph for Station 703 would have to be magnified 2000 times to be on the equivalent scale with all of the other graphs when magnified as indicated; and each of the smallest squares represents an MPN of 2000.

3. The solid graph lines, representing the "cycle" series of determinations, are on the graphs for Stations 703, 16, 20, and 605. The long-dash graph lines represent the "scattered" series of determinations on all charts. The short-dash graph lines are the extrapolated extensions of the graphs and the conventionalized area limits of the tidal cycle of 12-42 solar hours. Each determined MPN point is indicated by a short line crossing the graph-line. The dates and MPN for these points are noted in the right hand margin.

4. The symbols along the bottom of the graph indicate the twelve divisions of the tidal cycle, from the beginning of the flood to the end of the ebb.

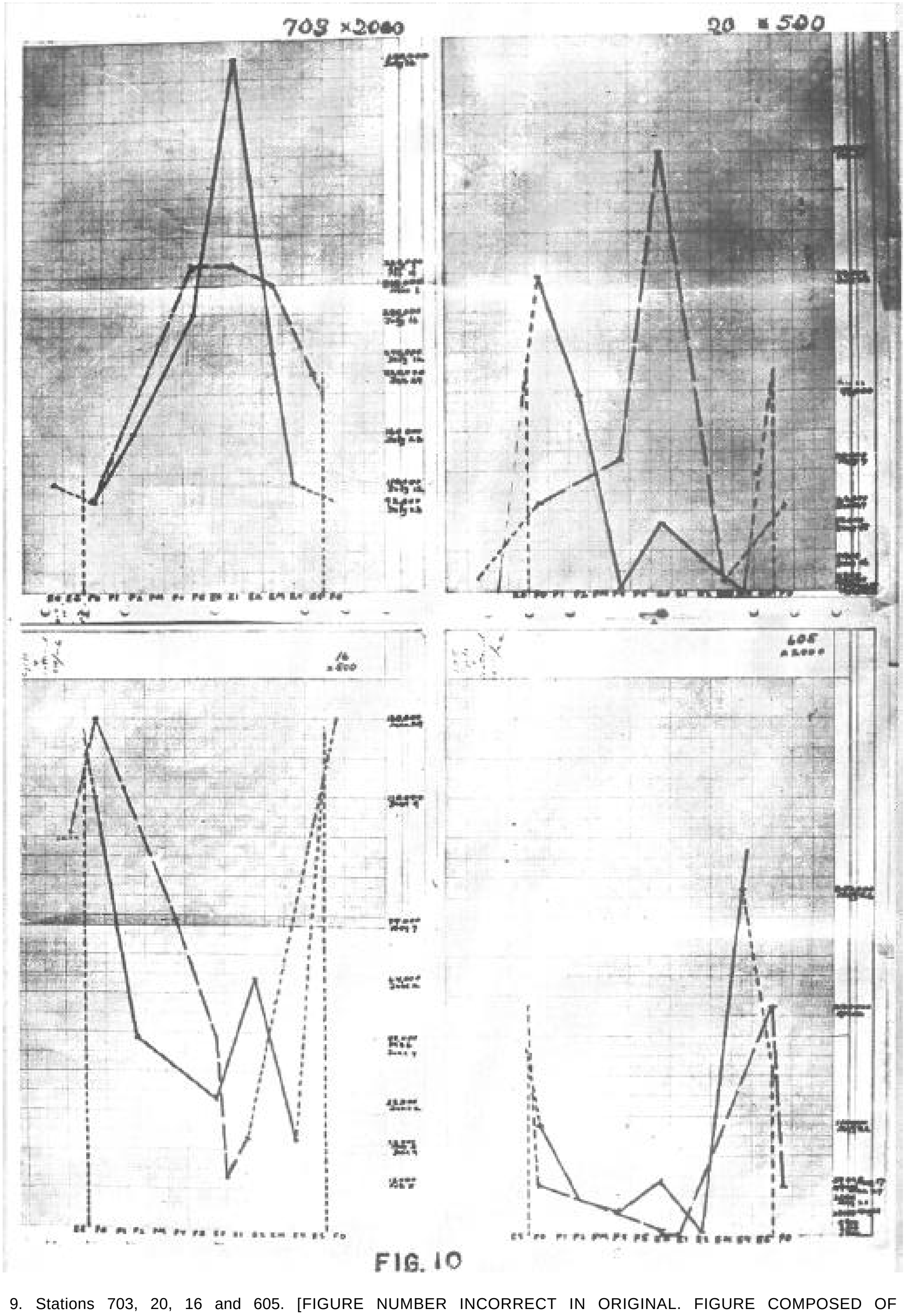


Figure 9. Stations 703, 20, 16 and 605. [FIGURE NUMBER INCORRECT IN ORIGINAL. FIGURE COMPOSED OF FOUR PHOTOGRAPHS GLUED TO THE PAGE. PHOTOGRAPHIC MATERIAL DARKENED AND FIGURE HAS BECOME DIFFICULT TO INTERPRET. NO CAPTION IN THE ORIGINAL. THIS IS BEST SCAN POSSIBLE OF ORIGINAL. SEE NEXT PAGE FOR INTERPRETATION.]

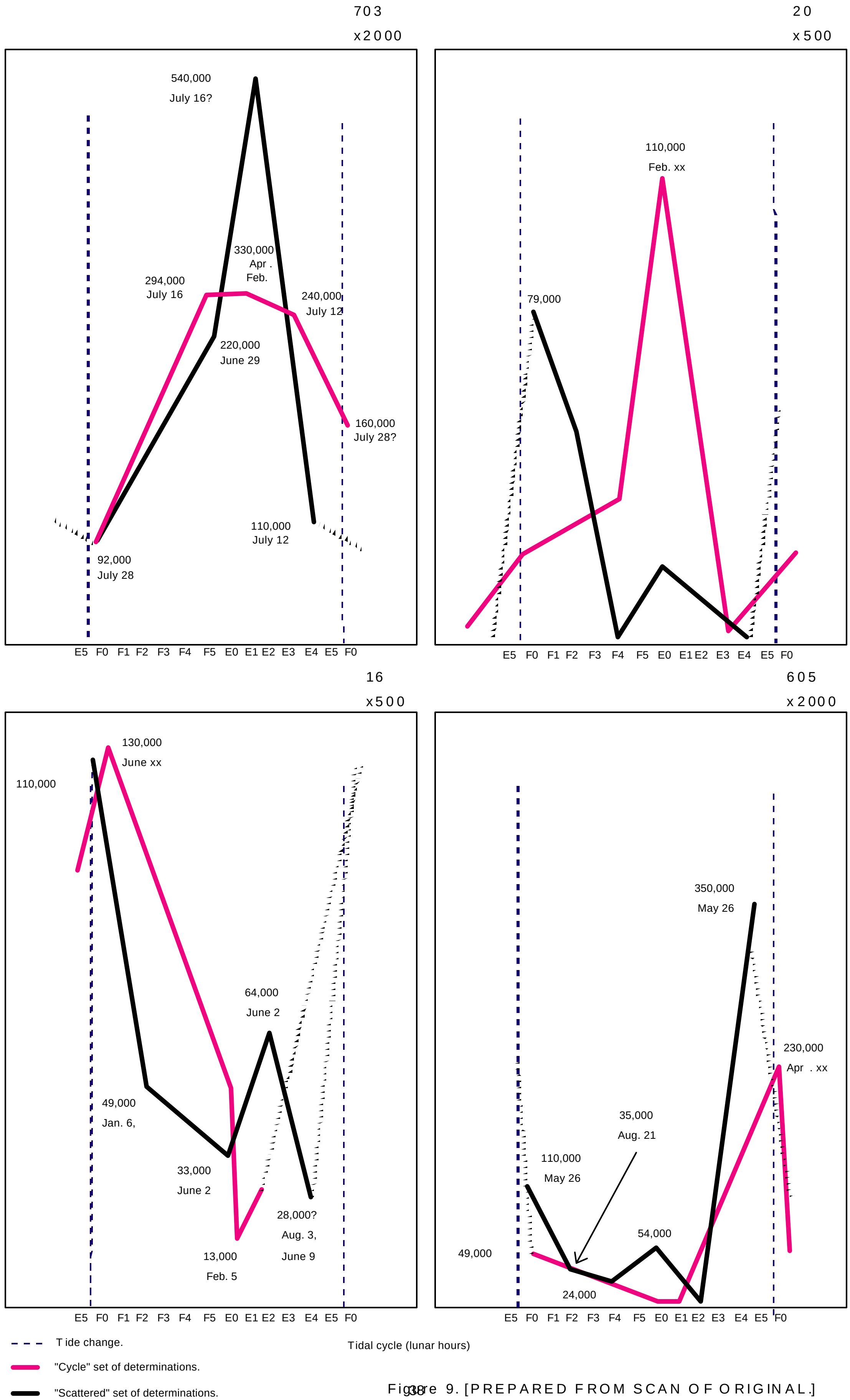


Figure 9. [PREPARED FROM SCAN OF ORIGINAL.]

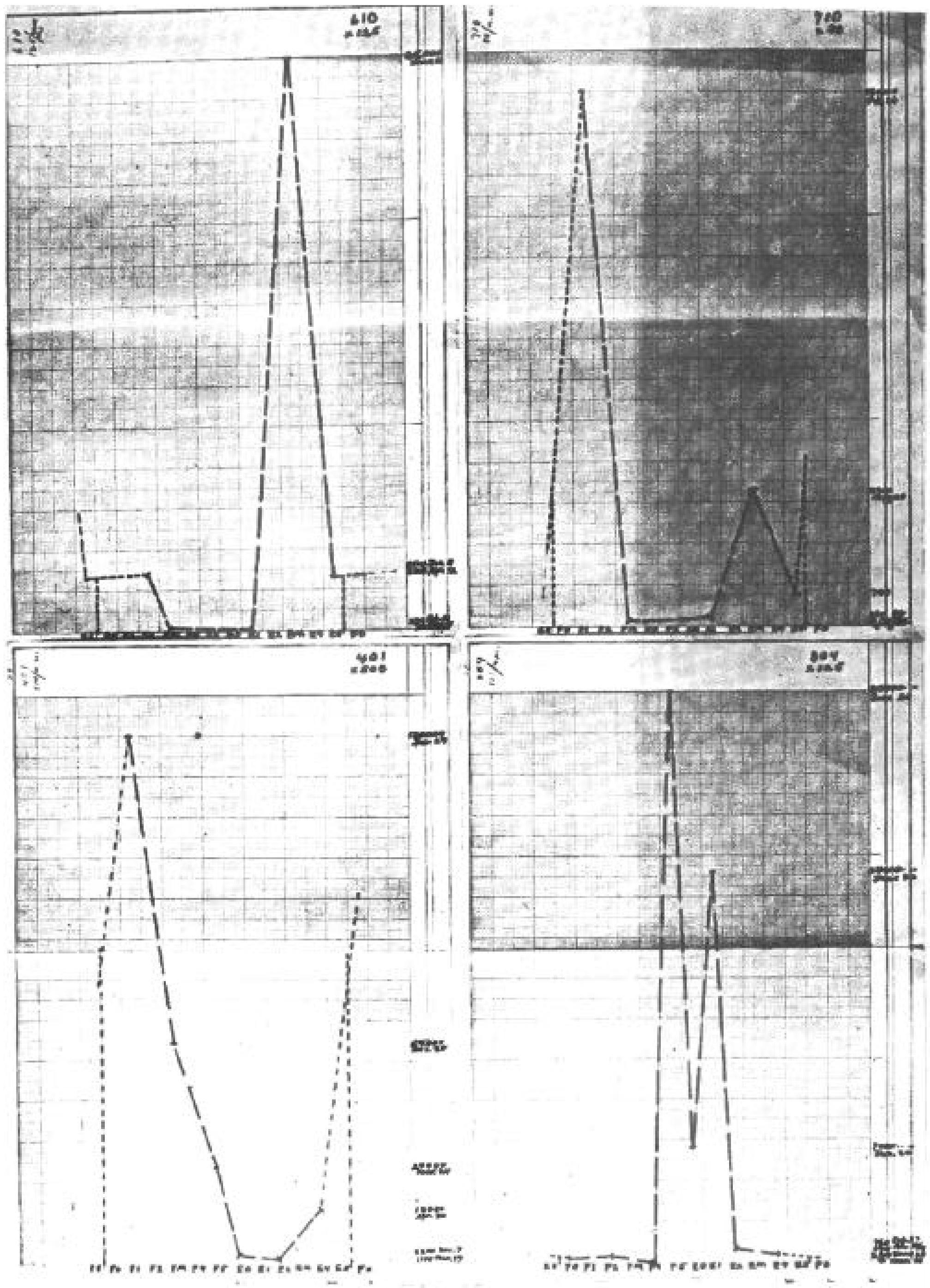
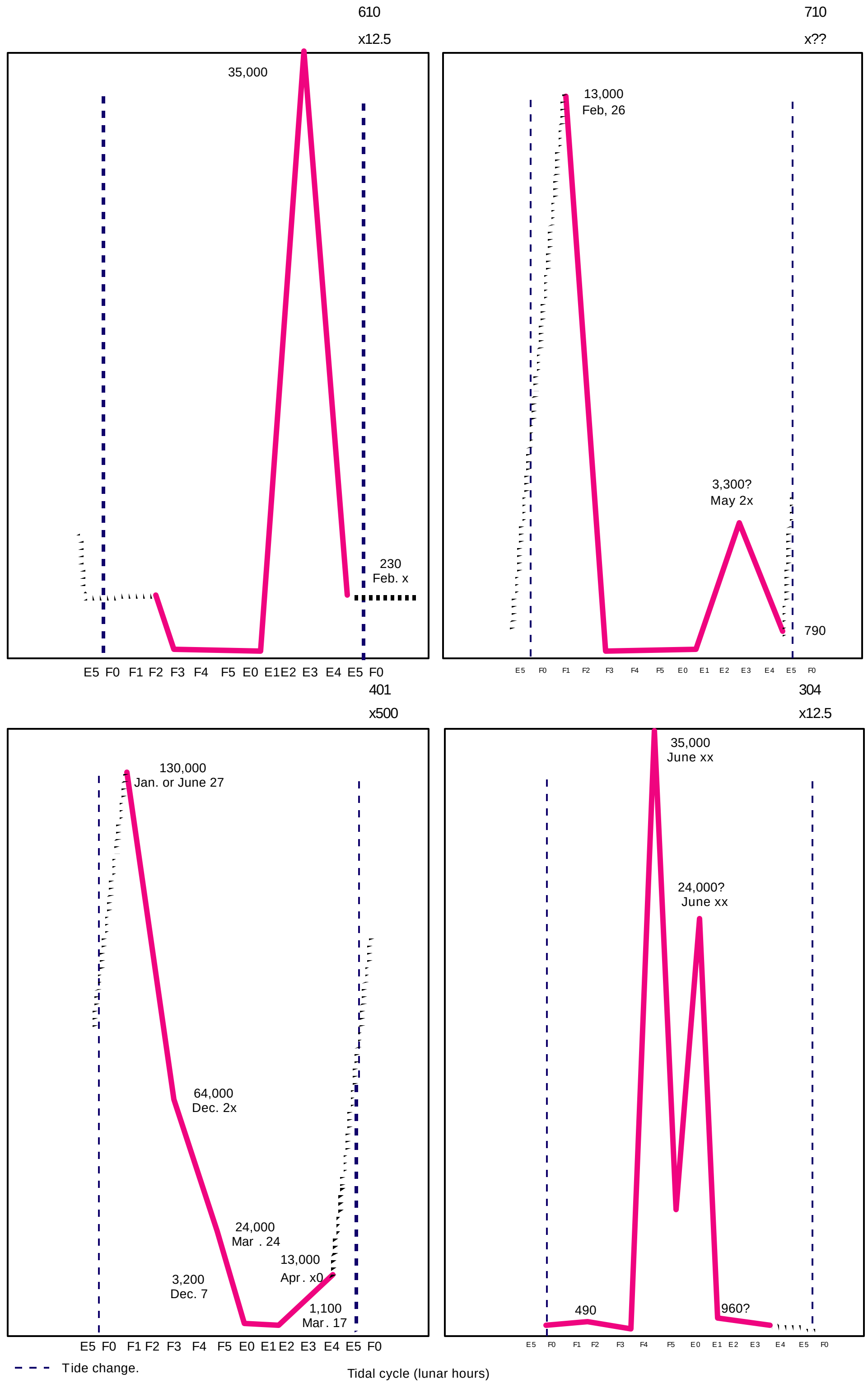


Figure 10. Stations 610, 710, 401 and 304. [FIGURE NUMBER INCORRECT IN ORIGINAL. FIGURE COMPOSED OF FOUR PHOTOGRAPHS GLUED TO THE PAGE. PHOTOGRAPHIC MATERIAL DARKENED AND FIGURE HAS BECOME DIFFICULT TO INTERPRET. NO CAPTION IN THE ORIGINAL. THIS IS BEST SCAN POSSIBLE OF ORIGINAL. SEE NEXT PAGE FOR INTERPRETATION.]



Tide change.

"Cycle" set of determinations.

"Scattered" set of determinations.

Figure 10.[PREPARED FROM SCAN OF ORIGINAL]

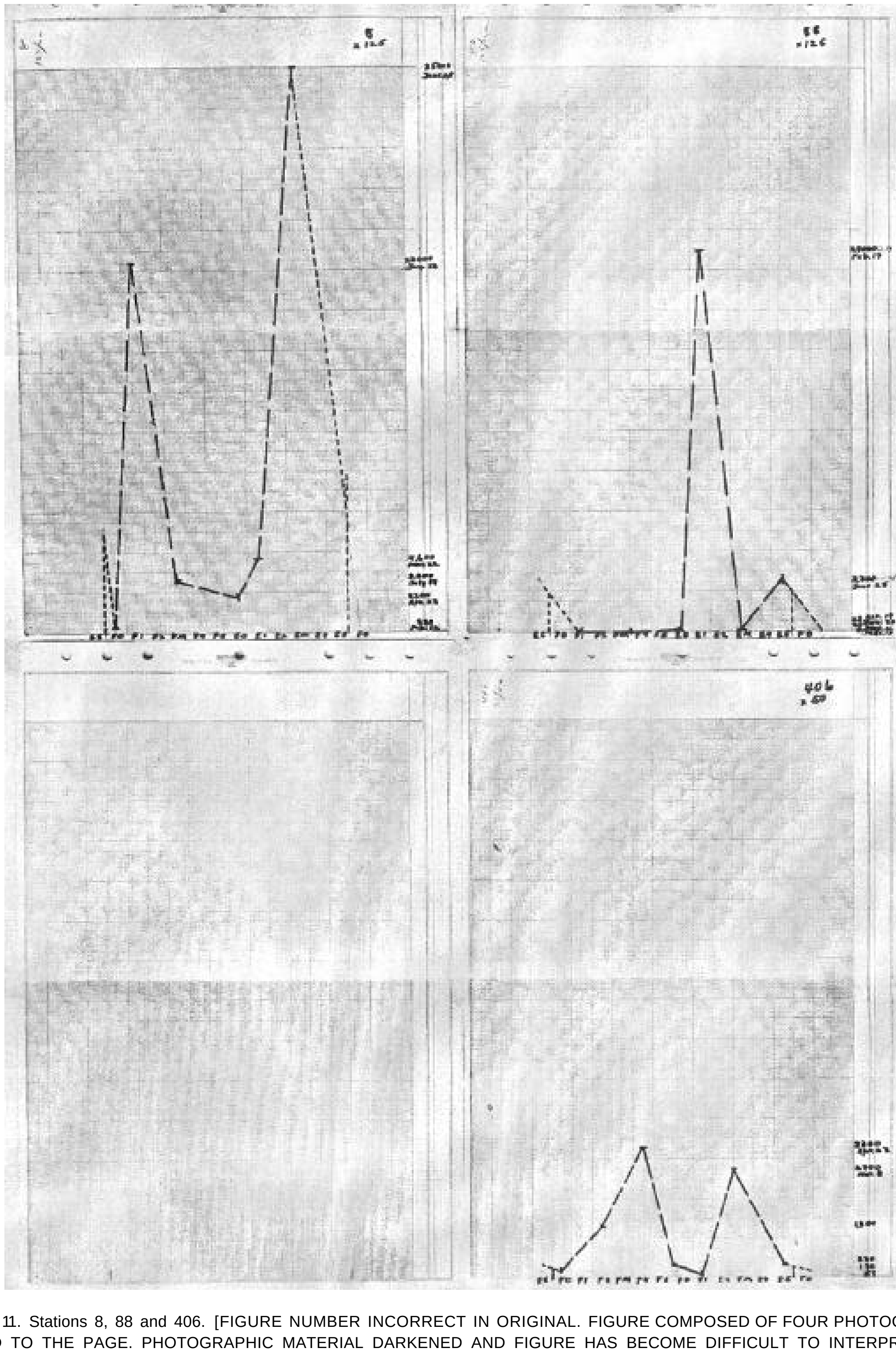


Figure 11. Stations 8, 88 and 406. [FIGURE NUMBER INCORRECT IN ORIGINAL. FIGURE COMPOSED OF FOUR PHOTOGRAPHS GLUED TO THE PAGE. PHOTOGRAPHIC MATERIAL DARKENED AND FIGURE HAS BECOME DIFFICULT TO INTERPRET. NO CAPTION IN THE ORIGINAL. THIS IS BEST SCAN POSSIBLE OF ORIGINAL. SEE NEXT PAGE FOR INTERPRETATION.]

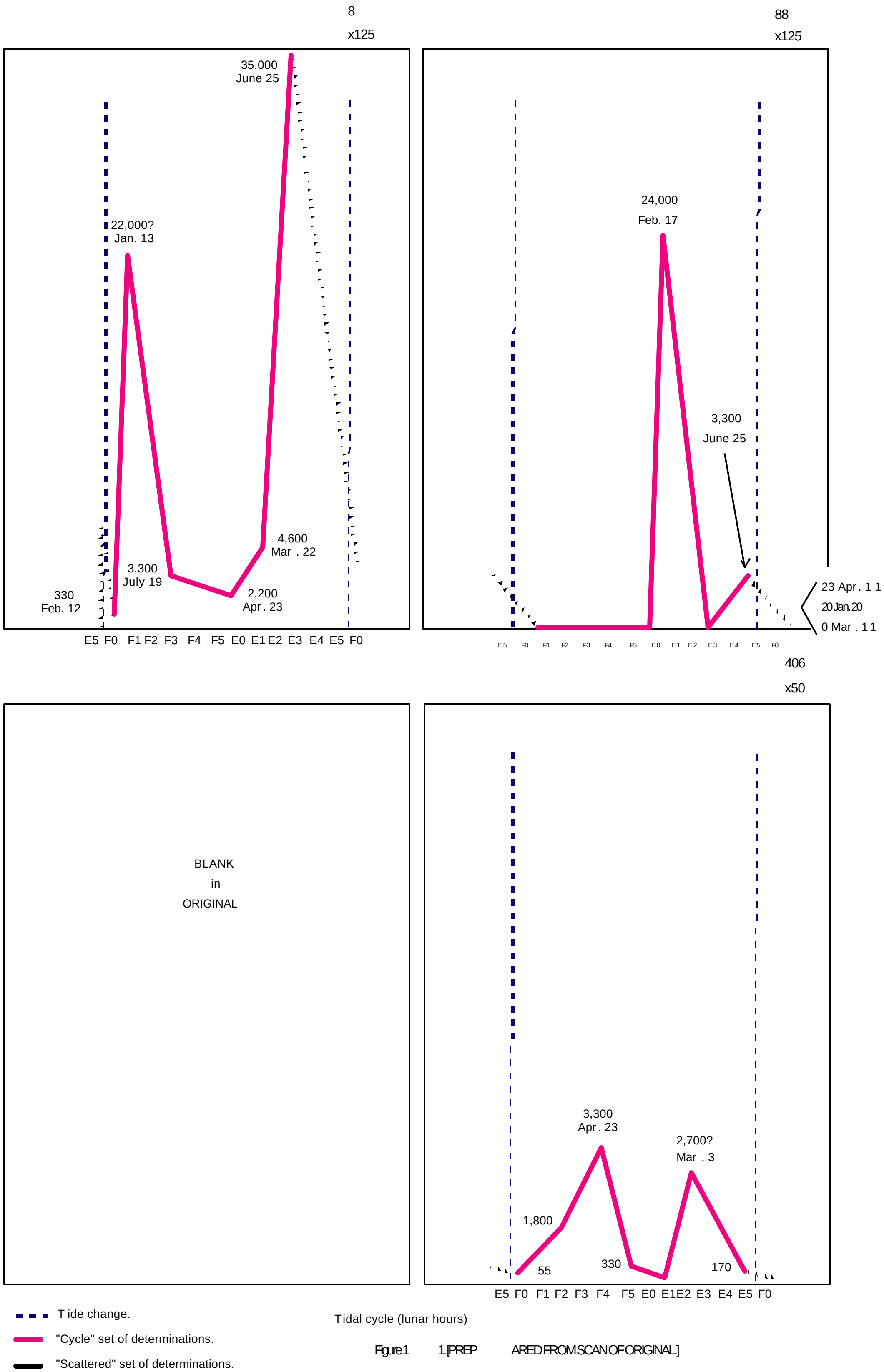


Figure 1 1.[PREPARED FROM SCAN OF ORIGINAL]

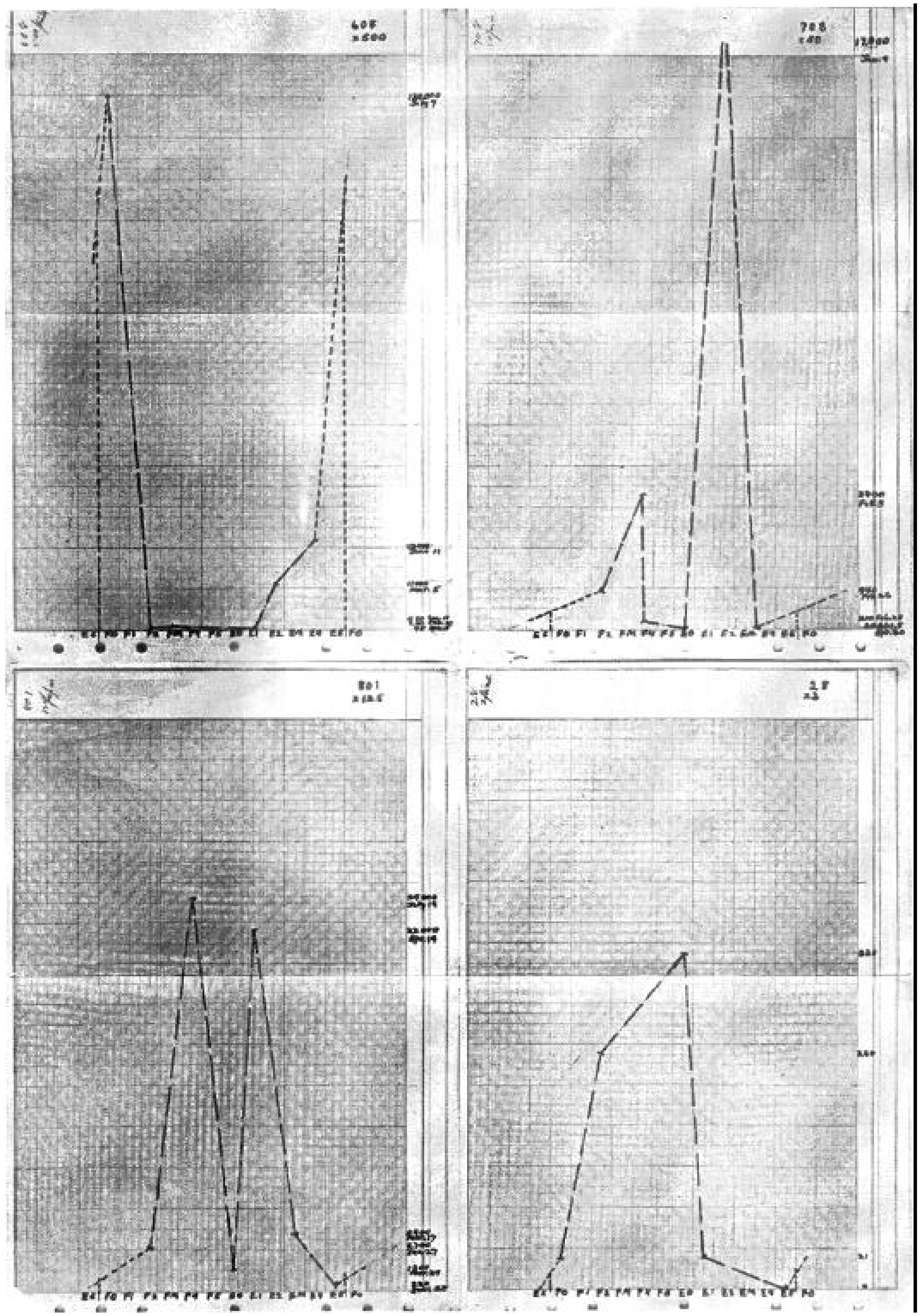


Figure 12. Stations 608, 708, 801 and 28. [FIGURE NUMBER INCORRECT IN ORIGINAL. FIGURE COMPOSED OF FOUR PHOTOGRAPHS GLUED TO THE PAGE. PHOTOGRAPHIC MATERIAL DARKENED AND FIGURE HAS BECOME DIFFICULT TO INTERPRET. NO CAPTION IN THE ORIGINAL. THIS IS BEST SCAN POSSIBLE OF ORIGINAL. SEE NEXT PAGE FOR INTERPRETATION.]

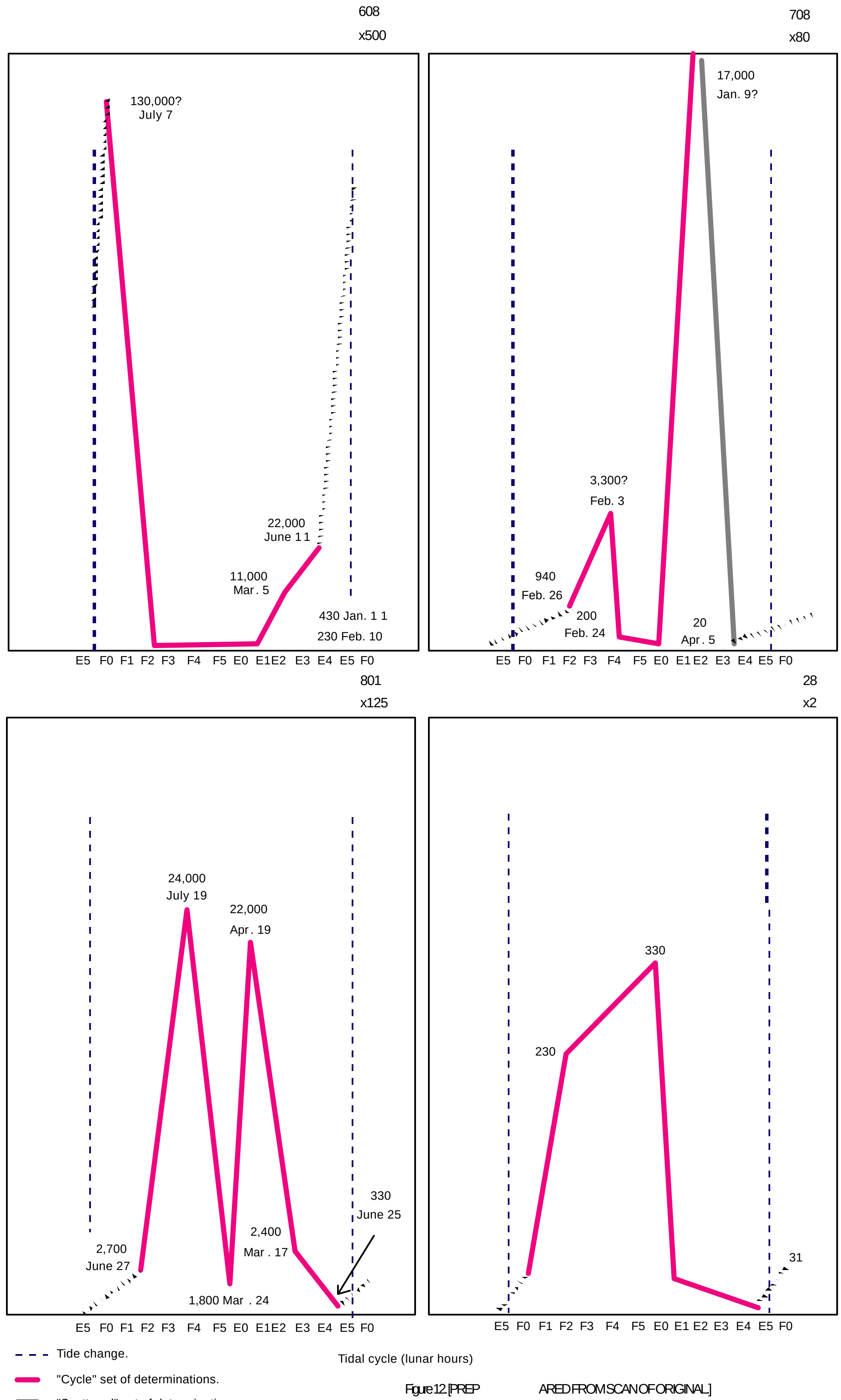


Figure 12 [PREP ARED FROM SCAN OF ORIGINAL]

In equation form: $PEI = \frac{a\,m}{12}$ in which:

a = planimeter determination

m = the MPN value represented by the graph-paper-unit. These values, in this study. which are, variously, 2.0, 50, 125, 500, and 2000, are indicated at the top of each chart. At Station 703, for example, the planimeter determination for the "cycle" graph was 36.4 (= a), and the smallest graph-paper-unit represents 2000 MPN (= m). Thus, $PEI = \frac{(36.4)(2000)}{12} = 6066$.

Any portion of the tidal cycle at a given station may be determined in terms *of* the PEI using the same general method as described for the total PEI. These partial PEIs may be equated in relation to the total PEI as needed to indicate their pollution effectivity. The total "Pollution Effectivity Index" for these stations is not the same as "Pollution Intensity" since the former is an integration of the MPNs of the entire tidal cycle over a more or less extended period of time, in this study several months.

The objection to the conventional "average" value is that it is based on too few samples. If a sufficient number of samples were taken throughout the entire tidal cycle, their mean would obviously approach the PEI value obtained graphically.

The phases of the tidal cycle are designated on the graphs and in the tables by the hydrographic symbols of the successive lunar hours, F0, F1, F2, FM, F4, F5, E0, E1, E2, ER, E4, E5. The FM and EM phases constitute the strongest flood and ebb conditions respectively.

In analyzing the numerical results of this study it is assumed, on the basis of the results, that the general picture of pollution conditions at each station is essentially repeated in the successive tidal cycles. Such variations as occur at any given station appear to be minor quantitative ones which, in the main, do not influence the general integrated result. Shifts in the tidal phases of maxima and minima appear also to be of a type which do not distort the essential result. Major changes in the physical arrangement of land areas, such as the building of new islands would, however, be assumed to cause shifts of significance.

D. Results

A study of the MPN graphs demonstrates that at the different stations, often at geographically closely related ones, the maximum and minimum numbers differed markedly and occurred at different phases of the tides. At nine of the stations, double maxima occurred during the tidal cycle. The maximum and relatively high numbers of coliform bacteria persisted only for a very brief time at some stations, e.g., an hour or less, while at other stations they continued over several hours; similar differences of low numbers and minima occurred. These differences indicate that determinations of maxima, minima and averages based on a few samples only do not necessarily indicate the relative, effective pollutions as the various stations. The Pollution Effectivity Index (PEI) on the other hand, offers an integration of the relatively few actual MPN determinations and of the numerous MPNs between these actual determinations. Table XI gives a rapid conspectus of the main changes in MPNs at all of the stations during the tidal cycle, while Table XII gives the numerical data summarized for each station.

At many of the stations a certain population-number of coliform bacteria, of larger or smaller size, was maintained throughout the entire tidal cycle or through a considerable portion of the cycle, as a "continuous-load". (Column 5, Table XII). At some of the stations, on the other hand, the number dropped once or twice during the cycles at certain of them for a considerable period of the cycle, to a very low figures thus essentially preventing the establishment of a continuous- load. The total number of coliform bacteria beneath each of the peaks of the graphs, and above the continuous-load-area, may be designated as the “peak-load”. The relative importance of the peak-loads and of the continuous-load in producing the total sewage "contamination-load", at a given station, can be determined by a comparison of the PEIs of the areas which "measure" these loads. Thus in Figure 13, which is a conventionalized diagram of the relations of the peak to the continuous-load areas the triangular area (a) is the peak whereas the rectangular area (b) is the continuous-load area, and the PEI of each can be determined readily from the graphs.

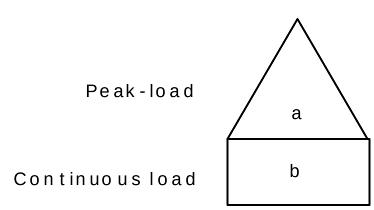


Figure 13. Diagram of peak-load and continuous-load areas.

For a comparative study of the results at the various stations the latter are conveniently grouped as follows by positional or dynamic factors:

Group 1. Stations 703, 20, 16, and 401, essentially at or near the main sources of sewage. pollution.

Group 2. Stations 605, 608, and 610, in Government Cut which is the main sluiceway for the heavily polluted water.

Group 3. Stations 801, 708, and 710, moderately polluted stations which appear to be placed at or near what may be called secondary exits.

Group 4. Stations 8, 406, and 304, an intermediate group selected for study because they constitute a transect through a portion of the bay north of the main pollution center.

Group 5. Stations 88, 28, and 66, at northern and southern extreme of the surveyed area, where only small amounts of sewage pollution or none might be expected.

The following comparisons and analyses of pollution conditions, based mainly upon the MPN studies, indicate some of the factors involved in the distribution sewage pollution in the bay. They are to be considered as a preliminary statement possible relationships mainly suggested by the MPN data.

<u>Group 1</u>. From the table of MPN Data it will be seen that, although Stations 703 and 20 are only about a half a mile apart, the pollution effectivity index of the latter station was only about eleven per cent of that of 703. If we make the reasonable assumption that the pollution at station 20 is derived from that at 703, it is clear that the bulk of the pollution at 703 is distributed northward to northeastward through the deep water way rather than southward to south-eastward.

As a source of sewage pollution, Station 703 exceeds all others. The nearest competitor was station 16, which over the twelve-hour tidal cycle was, however, only about 23 per cent as effective a center of pollution. This is particularly significant since station 16 is located close to a series of city sewage outfalls. Station 703, at the mouth of Miami River, gives a good indication of the pollution effectivity of the river which is the recipient of a very large proportion of the sewage of the city, Station 16, close to the dock area, likewise gives a similar cross section of the pollution effectivity of the sewage outfalls near the dock area. This station, however is located far enough out from the actual sewage outfalls to miss the temporary, irregular bacterial numbers associated with undiluted sewage. These two stations may be considered as the two main integrating sources of the pollution which is later measured at the surrounding stations farther out in the bay. This to be noted that at 703 the MPN builds up during the flood period to a maximum in the early ebb (El), thus indicating the dynamic action of the flood period holding back the dissemination of the sewage pollution.

From a consideration of the phases of the maximum pollutions at 703 and 16, it appears that although the maximum at 703 is being built up prior to the beginning of the ebb tide it is also supplying 16 with pollution during the final phases of the flood tide when there are from 240,000 to 280,000 coliform organisms to act as a reservoir from which to build up the secondary maximum of 64,000 at 16 during the early ebb tide.

<u>Group 2</u>. The three stations, 605, 608, and 610 in the Government Cut, which is the chief sluiceway for carrying away the sewage pollution, are interesting from the point of view of the distribution of coliform bacteria throughout the tidal cycle. At certain phases of the tide station 605 has a distinctly higher maximum than station 16, which is the nearest supplying station. It is evident, therefore, that station 703 supplies directly a significant portion of the pollution which appears at 605.

Stations 610 and 608 are rather effectively cleared of coliform bacteria during the P2 to El phases, down to an MPN of less than MO, and even at 605 the decrease from 350,000 to less than 1000 by the E1 phase is notable. Although Stations 610 and 608 are near one another in the cut, the phase of maximum pollution of 35,000 at 610 during EM was at a time when the MPN had built up to less than 22,000 at 608. This difference indicates that some source of pollution, not immediately apparent, caused this early maximum at 610. This conclusion is supported by a higher MPN at 610 during the F2 phase than at 608 during the FM phase on the same day in January and a higher BOD during the FM phase at 610 than at 608 during the F2 phase on the same day in February.

If we consider the raw data of maxima and averages only, it appears that this series of stations (605, 608, and 610) along the deep waterway, constitute an example of the control of numbers of pollution bacteria by the simple, direct, alternate action of flood and ebb tides. If however we consider in addition of the various phases of the tides at these stations as in the preceding paragraph, it is clear that the conditions at 610 are the resultant of these dynamic factors together with an additional pollution factor not evident at first. A Satisfactory explanation of this situation will await the more detailed hydrographic analysis of currents at this point.

<u>Group 3</u> At Station 708 there was a very rapid rise from E0 to a maximum MPN of 17,000 at E2 with an immediate sharp drop to a minimum MPN of about 20 at EM. Meantime at 710 there was a secondary maximum MPN of 3,300 at EM which developed mainly from the immediately preceding maximum at 708. It appears that approximately 20% of the maximum sewage bacterial mass at 708 passes through 710 during this phase of the tide.

Station 801 near the Miami end of the Rickenbacker Causeway on the north side is essentially at the southern limit of the main sewage pollution area. It has a varied record of MPNs

Table XI. Rise and Fall of MPN During the Tidal Cycle.

Station number		Beginning of Rise	Maximum	Beginning of Decline	Minimum
703	-c	F0	E1	E1	F0
	-s	(F0)	F5 to E1	E1 to E5	Rapidly to (E5-F0)*
16	-c, 1st	E4	E5-M	E5-F0	E0
	-c, 2nd	E0	E2	E2	E4
	-s	E0-E1	F0	F0	E0-E1
401		E2 to E4	Rapidly to F1	F1 to E0	slowly to E2
605	-c	E2	E4	E4 to F0	Slowly to E2
	-s	E1	E5-F0	E5-F0 to F0	Slowly to E1
608		Slowly E1 to E4	Rapidly to F0	F0 to F2	Slowly to E1
610		E1	EM	EM to E5	Slowly to E1
20	-c, 1st	E4	F0	F0	F4
20	-c, 2nd	F4	E0	E0	E4
	-s	Slowly Em to F4	Rapidly to E0	E0	EM
801	-1st	Slowly E5 to F2	Rapidly to F4	F4	Rapidly to E0
	-2nd	E0 rapidly to E1	E1	E1 to EM	Slowly to E5
708	1st	Slowly E4 to F2	Rapidly to F4	Rapidly F4 to F4	Slowly to E0
	2nd	E0	E2	32	EM-E4
710	1st	E5	F1	F1	FM
	2nd	Slowly FM to E1	Rapidly to EM	EM	E5
8	1st	F0	F1	F1 to FM	Slowly to E0
	2nd	E0	EM	M	EO
406	1st	F0	F4	F4	E1
	2nd	E1	E2-EM	E2-EM	F0
304	1st	F4	F5	F5	E0
2	nd	E0	E1	E1 to E2	slowly to F4
88	1st	E0	E1	E1	EM
	2nd	EM	E5	E5	E0
28		E5	E0	E0 to E1	Slowly to E5

"-c" - "cycle" set o£ determinations; "-s" – "Scattered" set of determinations.
"1st" – Primary Maximum; "2nd" - Secondary Maximum.
* Indicates the transition from one phase to the next.

Table XII. MPN Data.

		1	2	3	4	5	
Station Number		MPN Maximum	MPN Average	PEI	Hours at base of peak area	Estimated MPN continuous per 100 mL	
703	-c	540,000	237,000	6066	5.5	92,000	12 hrs
	-s	330,000	297,500	6250		200,000	9
16	-c	110,000	46,857	1394	2 peaks	33,000	12
	-s	130,000	58,800	1867	12 hrs	13,000	12
401		130,000	37,316	1048	7.5	2,000	12
605	-c	350,000	96,016	2450	3.0	3,100	12

	-s	230,000	57,108	1588	4.0	1,400	12
608		130,000	27,284	662	3.5	230	[NOT CLEAR]
610		35,000	8,421	180	3.5	3,300	7.0
20	-c	79,000	25,615	646	5.5, 2 hrs	790	11
	-s	110,000	41,825	946	4.0	2,300	12
801		24,000	8,955	202	2 peaks, 6 hrs	1,300	12
708		17,000	3,570	68	2 peaks, 3.5 and 2 hrs	940	5.5
						20	12
710		13,000	2,546	73	2 peaks, 4 hrs each	790	7.5
						130	12
8		35,000	9,776	289	2 peaks, 4 and 3 hrs	2,200	12
304		35,000	8,495	142	2 peaks, 4 hrs	200	11
406		3,300	1,112	34	2 peaks, 9 hrs	300	9
88		24,000	4,557	88	2 peaks, 7 hrs	20	9.5
28		330	131	3.4	7 hrs	31	7
66		33	10				

"-c" – "cycle" set of determinations; "-s" – scattered" set of determinations.

For explanation of this Table see succeeding page.

Explanation of Table XII "MPN Data".
Stations listed by number as shown in Figure 7.

Column 1 - The maximum MPN for each Station. For Stations 703, 16, 605, and 20, two sets of data were averaged separately and designated "c" and "s". The s-sets, like the samplings at all the other stations, include data scattered over several months. Each c-set was from samplings made during the summer and restricted to a period of two weeks or less.

Column 2 - Averages of MPN determinations at the various stations. For each station the determinations were made on samples collected at various significant phases of the tidal cycle, including in each case phases from both flood and ebb stages.

Column 3 - Each maximum on the graphs is at the peak of a roughly triangular area whose base may be at or near the zero line, or may be at a higher level. The estimated number of hours covered by the base or bases of these triangular areas are indicated in this column.

Column 4 - The MPN "Continuous Load" of coliform bacteria as estimated from the graphs/ This indicates the number of such organisms maintained at the station throughout the entire tidal cycle, or for the length of time indicated.

apparently depending mainly on variations in the direction and relative strength of the currents. Its low pollution effectivity index of 202 places it in general among the less polluted areas, although with a definitely higher pollution than 708, with its index of 68, which is much nearer the central areas of pollution. It is possible that much of the pollution at 801 during the ebb tide phase of E1 is derived from station 20, where the maximum MPN Of 110,000 with a strong southerly current was developed during the F5 and E0 Phases. In the June record of station 20 a maximum MPN of 79,000 was recorded in the F0 phase. This gradually dropped during the next two and a half hours to an MPN of 24,000. In the July record of 801 a maximum MPN, of 24,000 built up rapidly during the FM and F4 phases. Here too, the influence of station 20 may have been significant.

Group 4. Stations 8 and 304 constitute a clear evidence of the difference between maximum and average MPN records, on the one hand, and the pollution effectivity index on, the other. Both stations had MPN, maxima of 35,000 and averages of 9,776 and 8,495 respectively, which would indicate that they had similar pollution conditions. However, the PEI at Station 8 of 289, which was twice as great as that at 304 (PEI 142), shows that the stations are definitely different in their pollution conditions. An inspection of the complete records shows that their maxima were at almost opposite tidal phased and that the pollution at 304 was at a minimum, 760 and below, for nine out of the twelve hours while that at station 8 was considerably higher, 2200 or more, for most of that mm period of time.

Station 406, close to the Boat Slips of Miami Beach, was definitely less polluted than the other two in this group and less than station 88 which is about miles north on the Miami Beach side of the bay. Here again the PEI, gives a more accurate indication of the relative pollutions at 304 and 406, than the maxim or averages, a ratio of about 1 to 4 rather than of 1 to 8 or 20.

Group 5. Station 88 had a low MPN record except for about two hours at the E1 and E2 phases and a small secondary maximum at E5. The sources of these short time pollutions are at present obscure.

Station 28, near Dinner Key, has a low pollution record covering, however, about seven hours and with about 3.5 hours showing no pollution bacteria.

Station 66 records indicate a possible, very slight, irregular pollution with much of the time entirely free of indicative bacteria.

Sampling over Several Months Compared with Sampling over a Brief Period

Two periods of sampling were used at Stations 703, 16, 605 and 20 as indicated in Table XII. These are designated as the “s-set” and the “c-set”. The s-sets, like the samples at all of the other stations, were taken over several months time and at significant phases of the tidal cycle. The corresponding c-sets were taken at approximately corresponding phases of the tidal cycle, but over a period of less than two weeks, at Station 605 in May, at Stations 16 and 20 in June and at Station 703 in July.

A comparison of the two sets of data from Station 703, at the mouth of Miami River, which is in the area of greatest sewage pollution, shows that there was very little difference. This is best seen in comparing the integrated, PEI, records of 6066 for the c-set and 6250 for the s-set. Similarly for each of the three other stations under consideration the pollution conditions as indicated by the MPN data, were in the same order of magnitude for the two different periods of time covered by sampling. It is evident therefore that a few MPN determinations, planned to test the significant tidal phases and the various seasonal conditions, can give a satisfactory comparison of the sewage pollution at the various stations tested.

Determination of Biochemical Oxygen Demand

A summary of the significant results at various stations and as is shown in Table XIII. Many other determinations indicated very low BOD results and few significant correlations with other factors in the study. At the two “supplying stations”, 703 and 16, where the addition of new sewage material was regular, the BOD records were generally higher than elsewhere, ranging from 4.71 to 6.79. High MPN records did not in general correlate with the higher BOD records, except as just noted. At station 703 the BOD records for the summer period were higher than the winter and early spring records.

E. Comparison with results of a 1949 survey

The present condition of the bay in relation to sewage pollution, as compared with the seat recent prior study, is demonstrated in Table XIV. The 1949 records were tabulated for these principal stations in the central sewage polluted Area from the “Biscayne Bay Pollution Survey, Biscayne Bay, Dade County, Florida, May - October, 1949” by the Florida State Board of Health, Bureau of Sanitary Engineering, Jacksonville 1, Florida.

The Stations in the two surveys (1949 and 1953-1954) essentially correspond in geographic position as given in the table. However, station 605 was located at the southern edge of Government Cut and subject to direct flood from Miami River. The corresponding station 20 in 1949 was in mid-stream of the out, and home subject to rapid dilution. Moreover, from field observations, it was evident that at ebb tide especially, a strong current with heavy pollution flowed north and north-east-ward from station 703 toward Government Cut. Thus sewage polluted water would reach station 605 directly and would be much leas subject to dilution. These two factors evidently registered in the high MPN at station 605 and may account for the apparently greatly Increased average of MPN in the 1953-1954 survey as compared with the 1949 survey. All of the stations in this table of comparisons demonstrate a definitely greater sewage pollution in 1953-1954 than in 1949.

F. Conclusions

Standard Methods of the American Public Health Association were used for estimating the degree of pollution throughout the region but a new method has been developed for presenting results. MPN, values may fluctuate rapidly and extensively during the tidal cycle. Maximum and minimum values at a station are significant but, an average based on only a few samples my be misleading since a peak value nay be of very short duration. A truer average is obtained by integrating graphically for the whole tidal cycle, thus obtaining a

Pollution Effectivity Index PEI This concept is submitted as an improvement in presentation, yielding a better picture of pollution conditions and of the effective environment to which the organisms in a locality are exposed.

At most stations there is a definable tidal rhythm In the bacterial content of the water, but the phases of the tidal cycle at which minima and maxima occur vary from station to station in relation to the complex flushing processes in the area.

Samples taken at any station over a period of months agreed well with the samples made later at duplicate tidal phases, indicating that a fair picture of the tidal cycle MPN variations can be obtained by limited sampling over a period of many months provided that all phases of the cycle are represented.

Table XIII. Biochemical Oxygen Demand at Various Stations and Tidal Phases in Biscayne Bay.

Station	Phase	BOD	Dissolved oxygen (ppm)	Date	
703	F5		2.74	4/7	
	F5	6.77	8.10	7/16	
	E4-E5	2.03	1.76	12/2	
	E1		3.97	2/19	EM
	0.97	3.07	3/3		
	EM	6.79	6.86	7/12	E4
	6.11	6.49	7/12		
	E5	6.02	3.22	1/29	
16	E4	4.71	6.24	12/2	
401	F1	2.31	5.86	1/27	
	E4	1.38	4.72	4/30	
605	E0	1.20	4.20	5/17	
	F2	1.35	6.40	5/21	
608	F2	1.82	6.09	2/10	
610	FM	4.95	6.60	2/10	
20	F0	1.38	4.87	1/29	
	F4	3.98	6.20	5/7	
801	F4	1.13	6.12	7/19	
	E0	4.74	6.77	3/24	
708	EM-E4	1.36	5.87	4/30	
710	FM	5.51	5.56	2/24	
8	F1	2.75	5.46	1/13	
	FM	2.60	7.67	7/19	
	E0	2.45	6.40	4/23	
	EM	3.19	7.86	6/28	
406	F4-F5	2.07	6.12	4/23	
	E2-EM	5.85	6.24	3/3	
	E5	5.09	6.32	2/12	
304	F2	3.56	6.99	3/12	
	F5	0.55	4.72	6/30	
	E1	1.20	6.17	6/30	
88	E1	2.47	7.07	3/12	
	E0	1.67	6.34	1/20	
	E1	6.50	5.76	2/17	
28	F0	3.77	5.67	4/28	
	F4	0.84	5.89	7/6	
66	E5	2.02	6.40	4/28	

Table XIV. Arithmetic mean of MPN at selected stations in Biscayne Bay.

1953-54		1949		1953-54 as
Station	MPN	Station	MPN	a% of 1949
703	267,750	12	168,330	158
20	33,700	72	21,500	156
16	52,800	15	41,200	127
605	76,550	20	13,440	569
608	27,200	23	16,300	166
610	8,400	25	4,740	177
401	37,316	31	27,100	137
8	9,776	36	6,030	162

A comparison between MPN values obtained in the present survey and In 1949 survey indicates a very marked increase in pollution at all stations.

A general picture of the distribution of pollution In the area, and the extent of its cyclic variation, is presented. The significance of the results in relation to other conditions in considered In Section DISCUSSION AND CONCLUSIONS.

IV. MACROORGANISM STUDIES

J. Kneeland McNulty

A. General

A wide literature attests to the "abnormal" physical, chemical and biological effects of the entry of pollutants into natural waters. From evidence cited by Bartsch (1948)[1], Tarzwell and Duodoroff (1952)[2], Gainey [AND LORD] (1952)[3], and many others, reliable biological indices of water condition are always present but standardization of methods for their evaluation has not been attained to the degree realized in physical and chemical fields. In short, this phase of pollution studies appears to be an "infant science", as Bartsch points out.

A moment's reflection comparing estuarine to fresh-water stream conditions will underline certain important considerations.

Zonation, as defined for past fresh-water work, is mitigated by tidal mixing and flushing, the degree of mitigation being proportional to the efficiency of such mixing and flushing. This, then, is an essential step in any such study – a clear understanding of tidal movements.

Salinity changes provide a tool In estuarine not available to the fresh water worker, specially in estuaries such an Biscayne Bay, since virtually all fresh-water sources are polluted (except following heavy rains). These salinity changes are both a help and a hindrance: a help Insofar an tracing of water masses is concerned; a hindrance, In that the reactions of certain plants and animals to salinity changes and/or pollution' factors can be difficult to separate and define.

Nutrients, logically associated with sewage pollution, are normally relatively abundant In estuaries because of the drainage or large inland areas. A complete understanding of their availability from sewage sources in rarely possible except in a study such an the present one in which follow-up work after cessation of sewage influx in proposed an a corollary.

Fouling and marine borer organisms, either non-existent or relatively insignificant in fresh water, are an additional tool in estuarine waters.

Plankton, usually in estuarine waters, constitute another Important measure of ecological conditions.

Visualization of estuarine studies requires that we think not only in terms "zonation down the main channel from the source of pollution" but also in all directions from this source, an added complexity in intimate dependence upon the hydrography of the area. Its ultimate result is the construction of isolines op a by means of data from a large number of stations and statistical treatment the numerical data.

Without recourse to standardized methods and implementing a policy of covering as many parameters as possible, methods were adopted whereby three aims could be realized: (1) the gross quantitative population measurements of plankton, bottom organisms, fouling organisms, marine borers and fish; (2) the amassing of hydrographic, bacteriological and chemical data along with the biological parameters; and 3) qualitative comparisons of the fauna and floras the purpose being discovery of indicator populations and perhaps Indicator species.

Gross quantitative population analyses are now possible and will be presented, subject to future revision as additional data are obtained, A large body of hydrographic, bacteriological and chemical data are available, as shown in preceding sections. Some use can be made of these now but their full usefulness has not yet been realized. The concept of indicator populations and indicator species, toward which there is a considerable mass of data, requires further work.

B. Materials and Methods

Bottom sampling has been done with a Petersen grab, the open jaws area measure being 27.5 x 27.0 cm, handled from the boat by means of a manually operated portable block and tackle hoist. Samples delivered to the boat were deposited In a wooden box measuring about 1.5' long 1' wide and 9" deep, with bottom and sides fitted with sheets of Monel screenings aperture size 0.7 mm^2. Manual "sluicing" of the mud in this box produced a satisfactory residue of bottom flora, fauna, shell fragments and organic debris. At least five grab hauls were taken at each station, living animals and plants were removed from this residue In the field, deposited in bottles and brought back to the laboratory for analysis. Laboratory work involved three steps: (1) separation into major groupings; (2) recording number and size range of individuals and volume of living tissue for each species; (3) computing volume of living tissue per square meter of bottom. Preliminary work was done (on mollusks particularly) so that correction factors of reasonable accuracy could be applied for shell and skeletal volumes.

Data for pH were obtained in the field using a Beckman portable meter. Samples for this purpose were taken from the top few centimeters using an underway sampler. Samples for sand-silt fractions were taken from mud delivered by the Petersen dredge. An entire dredge-full of mud was dropped into a bucket, mixed thoroughly, and a small amount bottled and preserved for laboratory analysis. Analysis consisted of gently washing the sample on a 62-micron sieve with a jet of approximately 1 liter of water. The silt-laden water was suction-filtered through a coarse filter paper used in bacteriological work to remove foreign matter from hot agar culture medium (exact specifications not given by manufacturer). Calculations were based on the separate weights of sand and silt after drying for at least 48 hours at about 40 °C.

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[1] Bartsch, A,F., 1948. Biological aspects of stream pollution. Sewage Works J., 20 (2):292.

[2] Tarzwell, Clarence M. and Doudoroff, Peters, 1952. Application of biological research in the control of industrial wastes. Proc. Nat. tech. Task Comm. on Indust. Wastes. Fed. Sec'y Ag'cy., P.H.S. Environmental Health Center, Cincinnati. O.

[3] Gaineys, Perey L, and Thomas H. Lord, 1952. Microbiology of water and sewage. Prentice-Hall, Inc., New York. Pp.xi / 430.

Plankton samples have been obtained with the Clarke-Bumpus sampler and No. 2 net at a uniform depth of about 2.5 ft (about 76 cm). This depth was chosen from practical necessity: shallow enough to stay off the bottom at shoal stations and deep enough to avoid contact with underwater parts of the boat. The samples thus obtained ware analyzed volumetrically in the laboratory, results being expressed as milliliters of plankton per 10,000 liters of water strained. Laboratory procedure has involved three stops: (1) draining off water from the sample bottle through a piece of no. 2 plankton netting, leaving the wet but drained sample deposited on the net; (2) scraping the drained sample from the net with a sharp knife and transferring it to a 10-mL graduated cylinder; (3) calculating the volume of plankton by the difference between the volume of water added and that registered with plankton present. The Clarke-Bumpus cyclometer was calibrated according to standard methods.

Fouling data were obtained by exposing two glass panels per month at each station. The panels measure 8 x 9 in each, providing an effective area of 8 x 8 = 64 in^2 per side (approximately 10 x 10 cm = 100 cm^2 per side). Panel changes were accomplished within 1 to 5 days throughout the Bay. Depth of exposure was 2 to 8 feet at all stations except 610, where panels were left at about 20 ft. The method of exposure is modification of the original procedure. Individual float buoys were used at first, while all panels are now suspended from convenient pilings or markers, the writer having found that recovery rate is better and less maintenance time is required. Laboratory analyses of panels were similar to the analyses outlined above for bottom samples except that: (1) total fouling volume alone has been used; (2) no correction factors for calcareous or skeletal parts have been applied. Results are expressed in milliliters of fouling organisms per panel (both sides).

Borer attack rate has been studied by 8 x 8" yellow pine panels simultaneously with the glass panels about 2.5 feet off the bottom. *Teredo* and *Limnoria* counts have been made separately for each panel, *Teredo* counts being made microscopically. Results are expressed as total number of borer panel.

Fisheries studies have been conducted with a standard 20 foot shrimp trawl operated for 10-minute drags in selected areas. Initially, exploratory drags were made throughout the area, following which three transects were selected for repeated drags: (1) southward from Station 62; (2) cast southeastward from Station 605; (3) northward from Station 501. The fish so obtained were brought back to the laboratory for Identification and preservation.

C. Results

Quantitative studies were made of the plankton, fouling organisms, boring organisms and bottom organisms together with certain environmental conditions such as the pH and silt content of the bottom. A qualitative study also is in progress on the fouling and bottom organism to learn which species, if any, are valuable "indicator" forms.

Most types of organisms show very marked gradients correlated with intensity of pollution. This is somewhat obscured by the fact that gradients correlated with salinity would be expected even in the absence of pollution. In general, organisms (plankton, fouling, etc.) are relatively scares at the centers of pollution, much more abundant in areas of moderate pollution, decreasing to normal abundance in clean water. The correlations with pollution, salinities, etc., are discussed in fuller detail in Section V – DISCUSSION AND CONCLUSIONS. Tables XV thru XVIII summarize gross quantitative results of bottom, fouling, plankton and marine borer studies. Table XVIII, listing species of fish, does not give the gross quantitative aspect because it was rare to obtain three or more fish per drag in the polluted areas, insufficient numbers for quantitative treatment.

Table XV. Data summary of bottom organisms in Biscayne Bay, April thru June, 1954.

Sta.	Total No. Zoo/M^2	Total Vol. Zoo/M^2	No. Spp. Zoo/M^2	Total Vol. Plants/M^2
28	13.5 indiv.	10.3 mL	3	none present
66	43.2	17.6	6	none present
801	91.0	16.2	10	105.0 mL
703	81.0	9.5	3	none present
20	135.0	46.4	12	none present
708	110.7	24.8	9	none present
710	16.2	10.3	4	26.5 mL
16	62.1	6.5	11	none present
605	78.3	43.5	14	none present
608	248.4	60.0	19	148.5 mL
610	27.0	5.9	6	8.1 mL
401	369.9	100.4	26	67.7 mL
8	235.6	19.9	8	273.0 mL
304	91.8	52.1	19	118.8 mL
406	228.5	79.4	20	none present
88	70.2	21.6	11	472.5 mL

Table XVI. Data summary of sand-silt fractions and pH of surface mud in Biscayne Bay.

Sta.	PH	Weight sand	Weight silt	Total weight	Per cent silt
703	6.3	26.6	trace	26.6 g	0.0
20	7.6	57.6	6.0 g	63.6	9.5
708	7.45	85.4	10.195.5	10.6	
710	7.7	57.4	9.366.7	13.9	
16	7.4	57.4	6.063.4	9.5	
605	7.5	32.4	8.841.2	21.3	
608	7.4	50.9	7.458.3	12.6	
610	7.7	37.2	5.843.0	13.4	
401	7.65	43.4	2.646.0	5.7	
8	N.D.	70.1	2.572.6	2.9	
304	8.2	11.9	8.920.8	42.6	
406	8.1	82.6	9.492.0	10.2	
88	N.D.	38.3	6.945.2	15.2	

Table XVII. Data summary of fouling, plankton and borer means in Biscayne Bay.

Sta.	Fouling		Plankton		Borer	
	Mean mL/panel	No. Obs.	Mean mL/panel	No Obs.	Mean mL/panel	No Obs.
28	17.9	8	1.62	5	20.8	6
66	3.3	6	0.75	4	12.5	4
801	31.9	5	8.17	5	54.7	3
703	4.6	5	-	-	161.4	5
20	74.2	8	1.31	9	33.6	6
708	39.3	7	1.33	6	34.6	5
710	46.0	7	2.04	4	17.8	5
16	18.2	4	1.93	10	63.8	5
605	7.0	6	2.65	7	55.4	5
608	6.1	8	2.15	4	20.7	6
610	8.5	7	2.95	3	223.4	5
401	96.5	4	3.54	5	39.5	2
304	55.0	8	4.46	5	44.5	6
406	22.5	8	4.03	6	83.3	6
8	116.5	6	9.01	5	65.3	4
88	86.6	7	6.02	3	49.4	5

Table XVIII. Summary of qualitative fisheries data.

Species caught in polluted areas (PEI 500 – 1,000)	
Florida mojarra	*Ulaema lefroyi*
Striped grunt	*Gerres cinereus*
Spot snapper	*Haemulon sciurus*
Caesar (grunt)	*Lutjanus synagris*
Southern swellfish	*Bethystoma rimator*
Sea robin	*Spheroides spengleri*
Sheepshead	*Prionatus sp.*
Sea drum	*Pogonias cromis*
Additional species known to occur in polluted areas	
Silver mullet	*Mugil curema*
Silver mullet	*Mugil trichodon*
Black mullet	*Mugil cephalus*
Pinfish	*Lagodon rhomboides*
Cowfish	*Lectophrys tricornis*
Ten pounder	*Elops saurus*
Nassau grouper	*Epinephelus striatus*
Tarpon	*Tarpon atlanticus*
Needlefish	*Strongylura notatus*
Additional species caught in small numbers in Biscayne Bay gill net commercial fishery* (perhaps in polluted areas)	
Jack	*Caranx hippos*
Speckled trout	*Cynoscion nebulosus*
Broad shad	*Gerres cinereus*
Mangrove snapper	*Lutjanus griseus*
Permit	*Trachinotus goodie*
Common pompano	*Trachinotus carolinus*
Bluefish	*Pomatus saltatrix*
Spanish mackerel	*Scomberomorus maculatus*
Snook	*Centropomus undecimalis*
Moonfish	*Vomer setapinnis*
Sailor's choice	*Haemulon parra*
Spadefish	*Chaetodipterus faber*

* from Siebenaler, J. B., 1953. The Biscayne Bay commercial fishery. Florida State Board of Conservation, Tech. Ser. #6. Marine Laboratory, Univ. of Miami.

V. DISCUSSION AND CONCLUSIONS

The figures which follow are the basis for discussion and conclusions. All except Figure 16 have the following aims:

(1) To show key physical and biological parameters in a manner frequently used in studies of this kinds i.e., as transects through the areas of highest pollution.

(2) To add *another dimension" by grouping the three transects in series: transect I represents conditions north and south along the Miami shoreline; Transect II through mid-bay; and Transect III along the bay shores of Virginia Key and Miami Beach. One should try to visualize the figures as solid rectangles, Transects I and III representing outside surfaces and Transect II representing a plane surface parallel to and approximately halfway between outer surfaces. Reference to Figure 7 will aid in visualizing the transects in this manner. Distances are plotted from shortest water routes between stations, Miami River and Government Out serving as mid-points on all graphs.

(3) To emphasize relative values by scaling all data within the ranges found. For instances PEI values (the Pollution Effectivity Index of the preceding section) vary from 0 to 2,058; these and all intermediate values are scaled from 0 to 10. Use of this scale has simplified direct graphic conversion of variations along the chosen transects for all data in this study.

(4) To use the PEI as a constant for comparison throughout. This in related to MPN results as described In the preceding section.

Salinity. As mentioned above, virtually all fresh water entering the Bay except during heavy rains contains sewage, a fact which offered the opportunity to compare salinity to PEI. Weighted mean values of salinity from all available sources in this study have been used in Figure 14. It is clear from the figure that a close relationship of mean values appears only along the Miami shore, and there only partially. Eastward from the Miami shore, the relationship becomes even less clearly defined. The mean salinity data were treated in two ways: (1) as 10 minus the scaled values, and (2) as 1/mean sal., this value in turn being scaled from 0 to 10. While the reciprocal relationship gives a slightly better fits it Is still far from being inversely proportional to PEI Figure 15, comparing scaled salinity range values to the PEI also shows the lack of a clear relationship. As emphasized in the hydrographic section of this report. The salinity range remains relatively high in the most heavily polluted areas. The result is considerable mixing, flushing of such efficiency as to keep conditions from becoming septic and consequent wide fluctuations In MPN during the 12-hour tidal cycle, as shown in the bacteriological results. Figure 16 is one of several possible graphs of the saw type, introduced here to show that a sharp rise in MPN may or may not be accompanied by a corresponding drop in salinity. The mechanism appears to be somewhat an follows: Low salinity water, highly polluted, mixes rapidly with the waters of higher salinity In the Bay where the polluted waters rapidly lose their identity. with respect to salinity. In a more constricted, “tongue-shaped” estuary, lacking the many channels and small Islands of Biscayne Bay, a closer relationship between MPN and salinity might be shown.

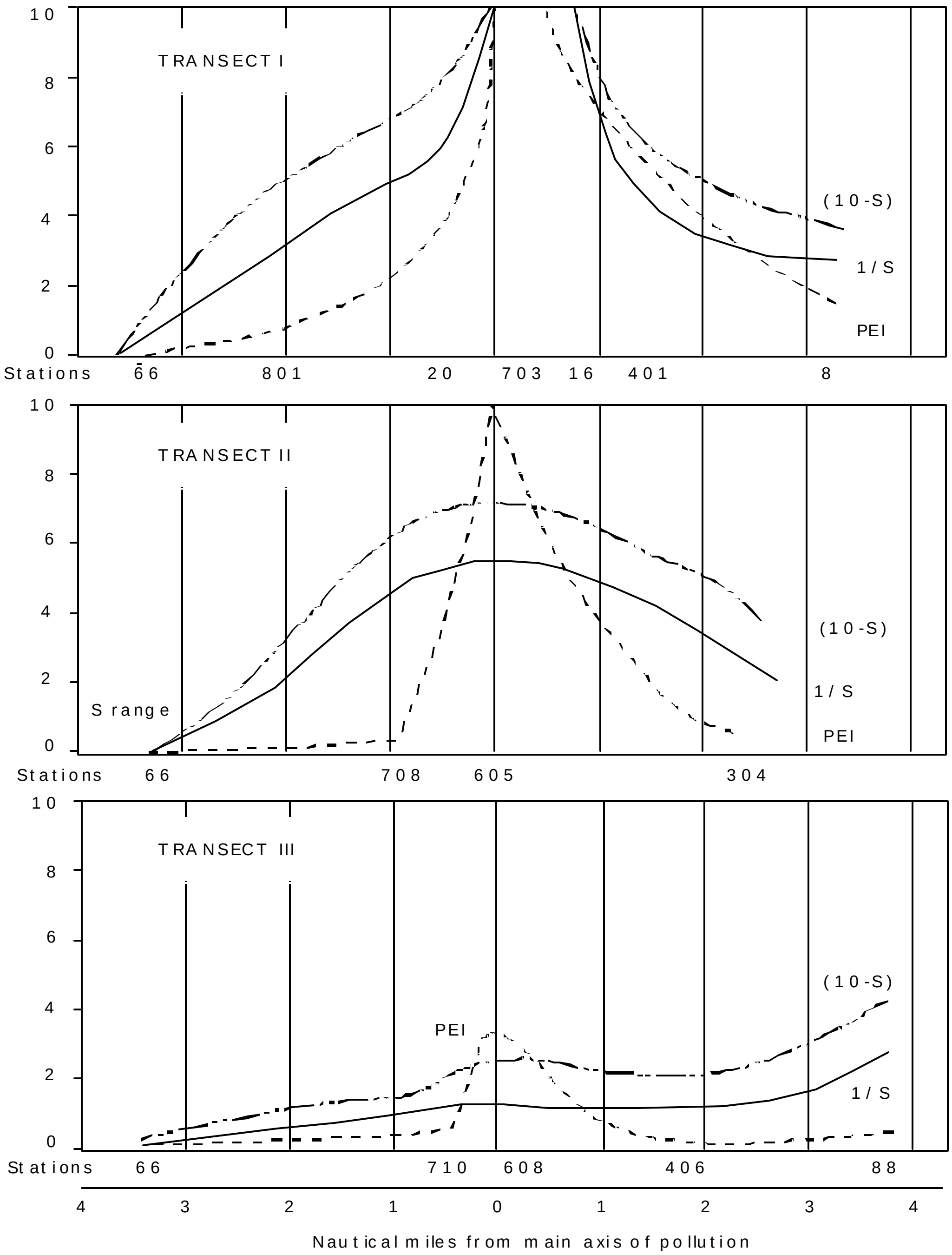

Figure 14. Salinity and Pollution Effectivity Index. Scaled values of 10 minus mean salinity (10 – S) and the reciprocal of mean salinity (1/S), compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	Mean Sal.	1/Sal. x 100
10	2058	32.4	3.1
0	0	21.9	4.8

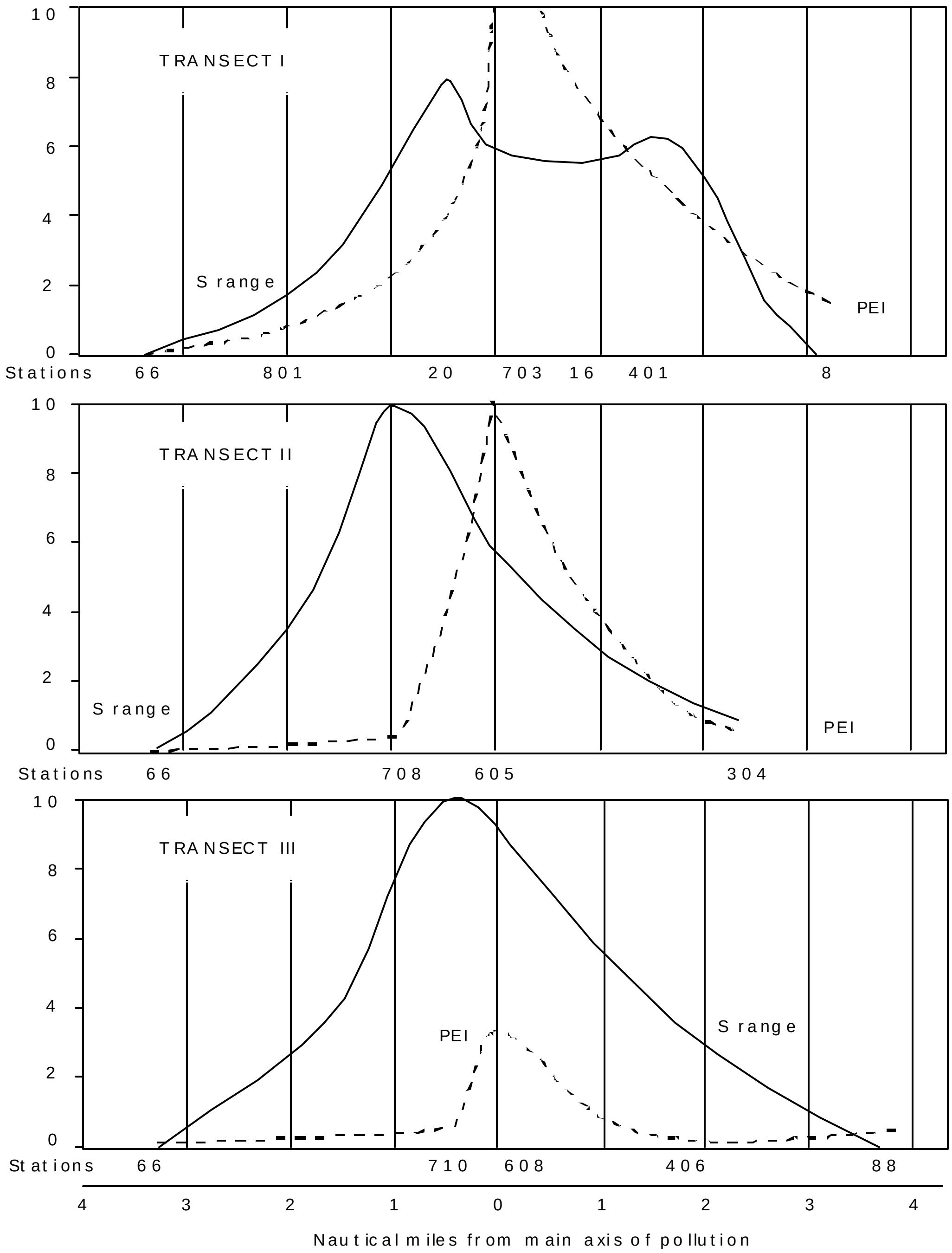

Figure 15. Salinity range and Pollution Effectivity Index. Scaled values of salinity range (S range) compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	Sal. range
10	2058	11.2 ppt
0	0	1.3 ppt

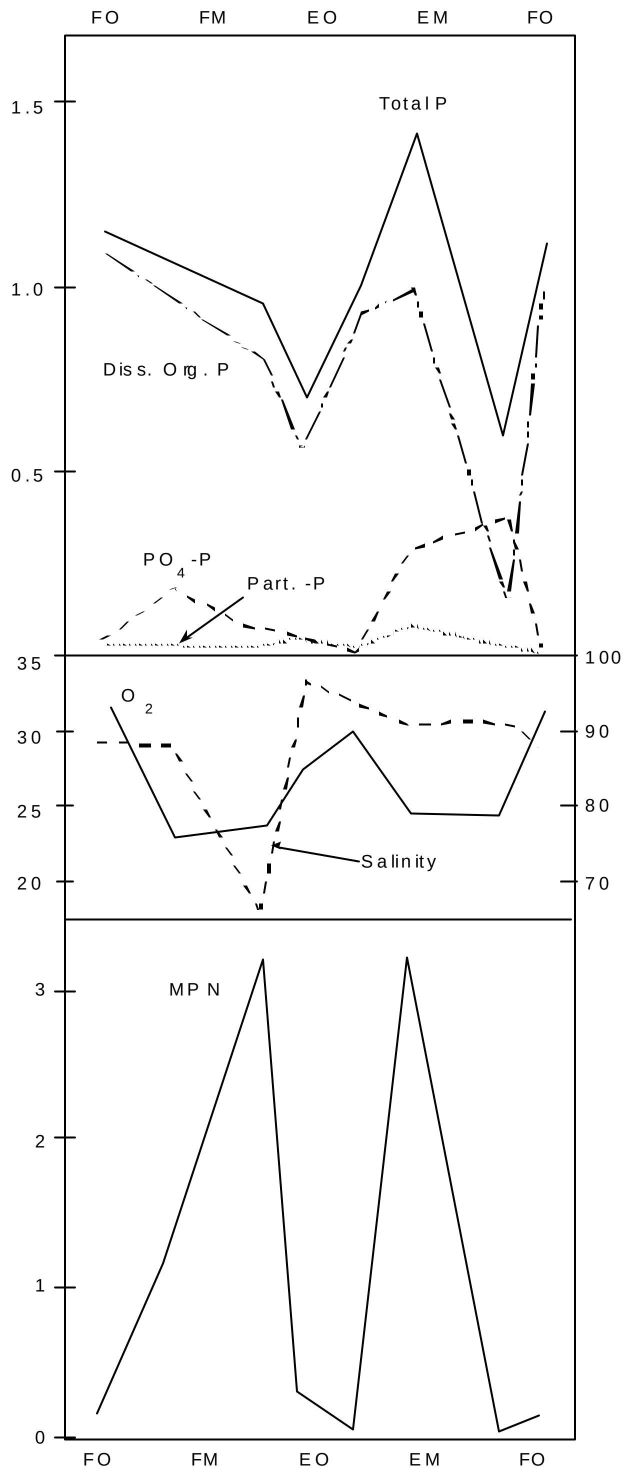

Figure 16. Changes through "one" tidal cycle at Station 406 and MPN, per cent saturation of oxygen, salinity, particulate phosphorus, phosphate-phosphorus, dissolved organic phosphorus and total phosphorus. By "one" tidal cycle is meant observations over many months (Dec., 1953 to July, 1954) using the combined sampling procedure described in the text.

Conclusion: There is some evidence of an inverse relationship between salinity and MPN at stations nearest the Miami River, but only a very general inverse relationship elsewhere. The polluted fresh waters entering the Bay quickly loose their identity with respect to salinity.

Dissolved Oxygen. Figure 17 illustrates the generally high level of oxygen saturation throughout the Bay. Only at and very near Station 703 is the septic level (below 40% saturation) reached. This fact means that most stations subject to pollution fall within the "recovery" zone. The graph is drawn from mean en data presented in the hydrographic section of this report. Values are expressed as 10 minus scaled oxygen saturation to allow direct numerical comparison of PEI to saturation percentages. As was true for the salinity values, the relationship is not numerically close.

Conclusion: Except for Station 703 and the immediate vicinity, where conditions are septic, oxygen saturation values well above the 40% level are found generally throughout the Bay. Mean saturation percentages do not compare accurately with numerical values for the PEI, hence oxygen values alone are not particularly valid in describing the ecological effects of pollution in the bay.

Phosphorus Components. These are high in the Miami River, as shown in Figures 18 and 19, but even higher at Station 8, where maximum values of all components were found. Station 8 is some distance from the nearest sewer outfall, but it receives sewage-laden water continually from both south and north. Mixing, however, is very slight. On the other hand, Government Cut (stations 16, 605 and 608) is subject to rapid and thorough mixing; hence its nutrient supply, as indicated by phosphorus components, diminishes rapidly outward from the Miami shoreline. A measure of the phosphorus components supplied by sewage will be possible only when final studies are made, after sewage no longer enters the bay.

Conclusions: Phosphorus component, originally higher in sewage-laden water than in cleaner waters nearby, are rapidly diluted by tidal action. Areas north of Venetian Causeway along the Miami shoreline show maximal values, the combined resultants of little tidal mixing and probably, active regeneration of these components in excess of the requirements of organism in the area. That part of the phosphorus components supplied directly and indirectly by sewage alone can be determined only after sewage no longer enters the Bay.

Fouling and Plankton. Fouling intensity measurements have yielded data which appear to vary rather closely with PEI data (Figure 20). The uniformly depressed values throughout zones of highest pollution, taken together with abrupt increases on either side, have occurred most definitely in 1954 during June and July, the year's months of maximum fouling intensity. The plankton data along the Miami shoreline do indicate the areas of heaviest pollution, but less sharply than does the fouling. Away from the Miami shoreline the effects are less closely correlated with PEI, although a marked trend toward higher plankton populations northward from Station 66 was noted.

Conclusions: The data show a marked change In fouling intensity an transects through the axis of pollution, the intensity being abruptly less with increasing pollution. This effect was most marked during the 1954 months of heaviest fouling, June and July, and warrants more detailed study. Plankton volumes were markedly less than elsewhere in the most highly polluted areas, but showed no abrupt changes with respect to moderately high and lower pollution intensities. Thus, the effects of pollution on plankton were much less apparent than on fouling organisms.

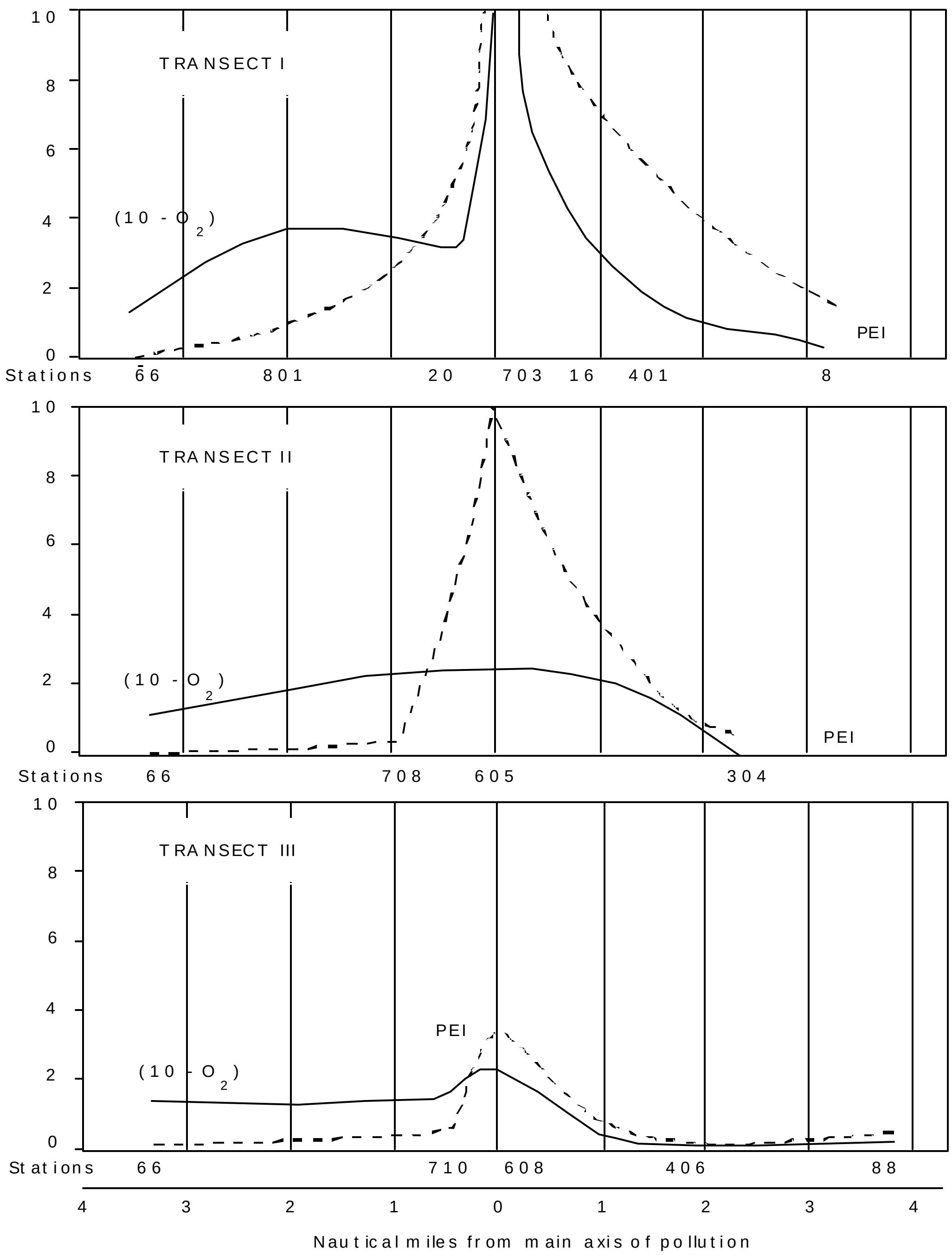

Figure 17. Per cent saturation of oxygen and Pollution Effectivity Index. Scaled values of oxygen percentages shown as difference from 10 (10 – O_2) compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	% Sat. O_2 (mean)
10	2058	86.2
0	0	56.5

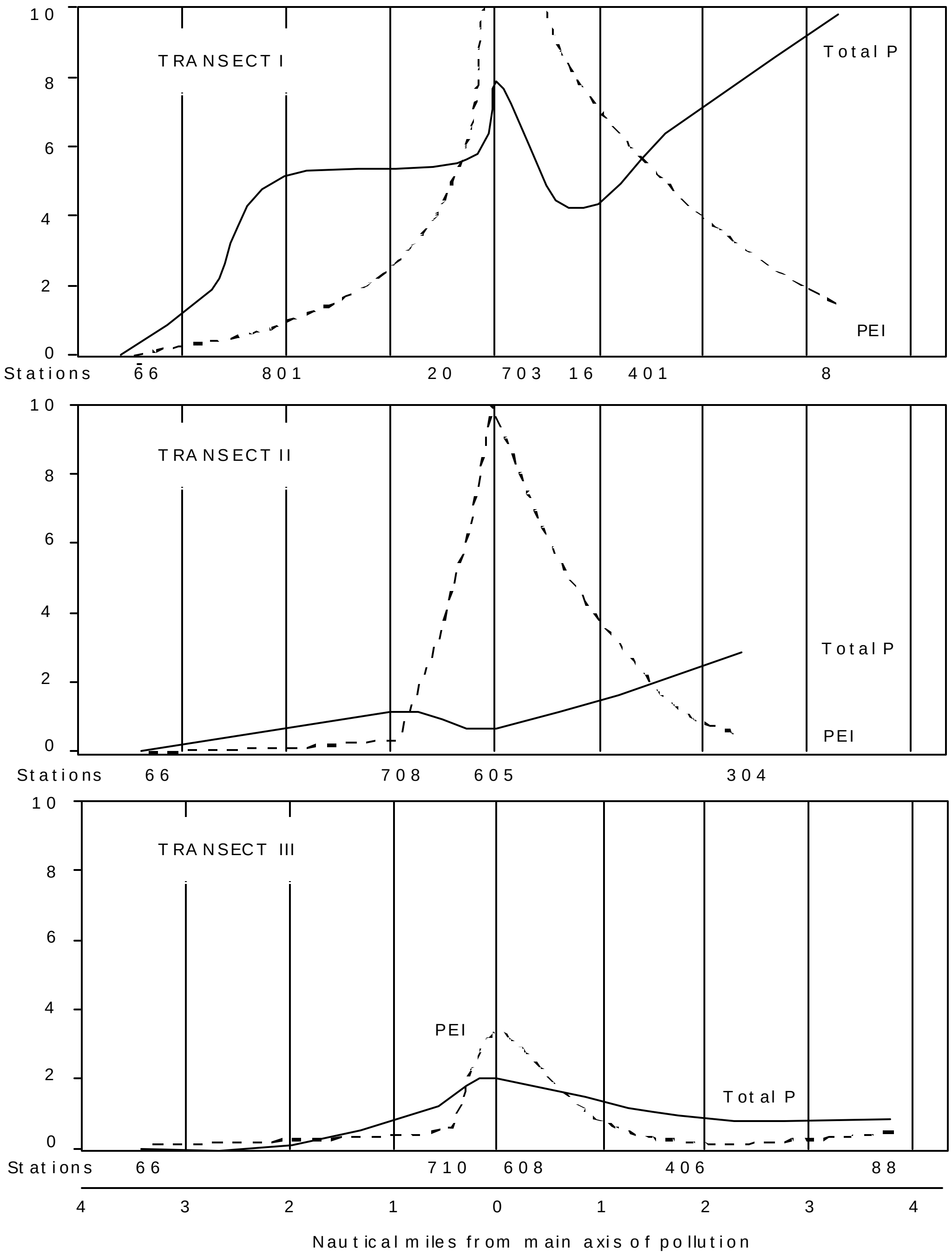

Figure 18. Total phosphorus and Pollution Effectivity Index. Scaled values of total phosphorus (Total P) compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	Total P
10	2058	2.987 µg-a/L
0	0	0.778 µg-a/L

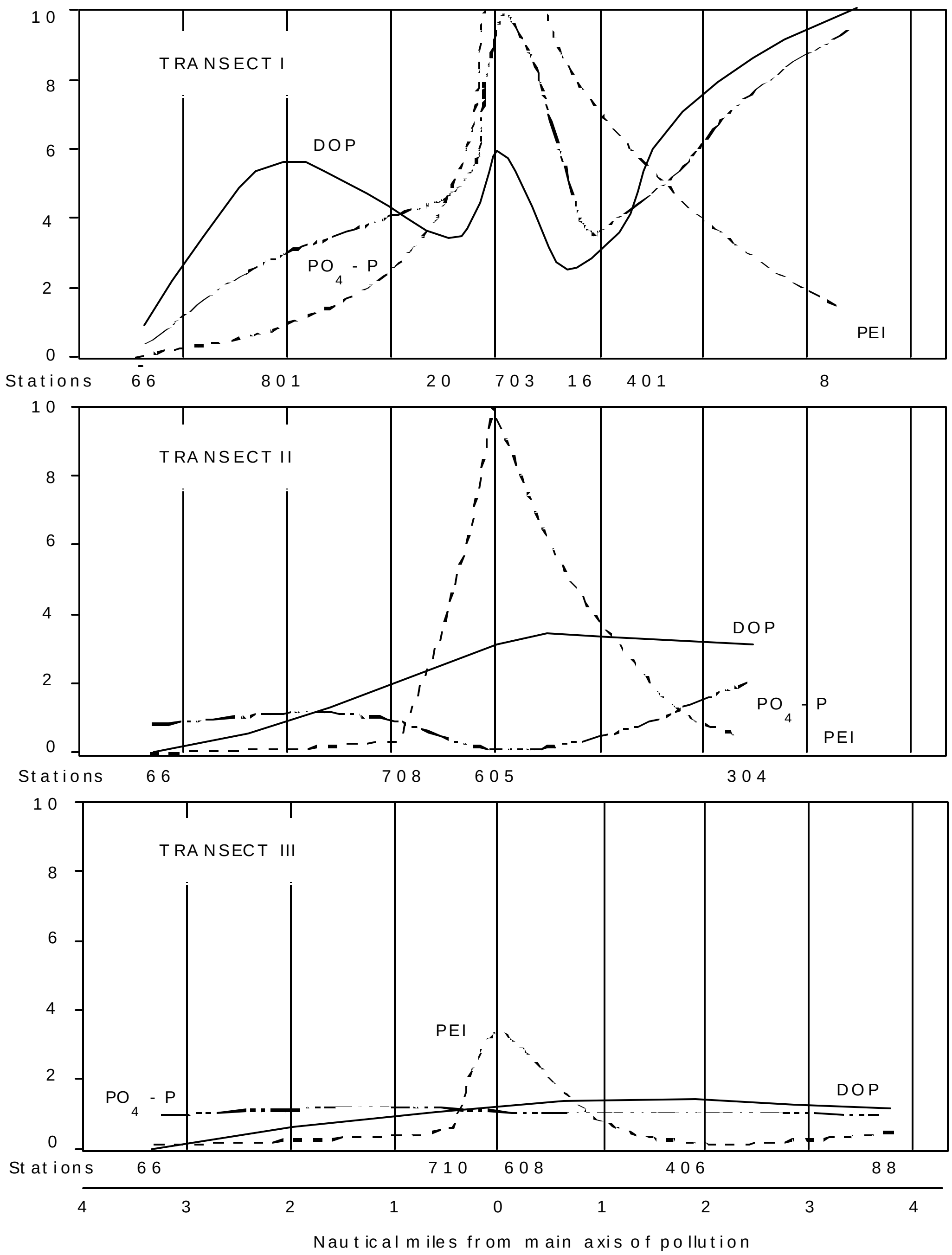

Figure 19. Phosphate-phosphorus, dissolved organic phosphorus and Pollution Effectivity Index. Mean values for phosphate-phosphorus (PO_4 – P) and dissolved organic phosphorus (DOP) are compared with the Pollution Effectivity Index according to the following scale:

Scale	PEI	PO_4 – P	DOP
10	2058	1.10 µg-a/L	1.96 µg-a/L
0	0	0.03 µg-a/L	0.63 µg-a/L

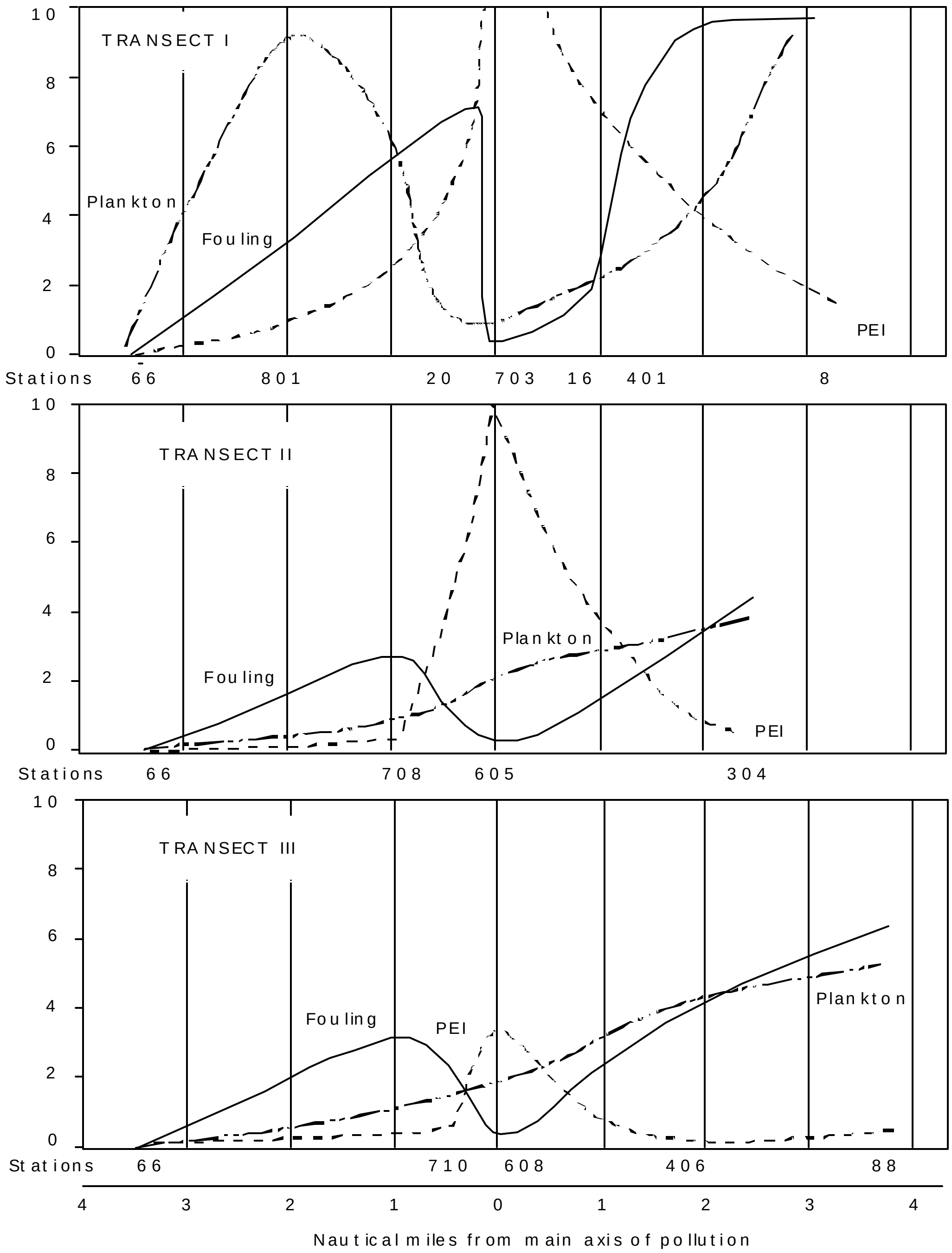

Figure 20. Plankton volumes, fouling volumes and Pollution Effectivity Index. Scaled values of mean plankton volumes and mean fouling volumes are compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	Plankton vol.	Fouling vol.
10	2058	9.01 mL	108.7 mL
0	0	0.75 mL	3.6 mL

Bottom Animals and Plants. Bottom animals, hardiest of parameters studied showed marked population increases immediately outside the most heavily polluted areas, dropping gradually from those maxima as bottom plants increased in importance. No plants and few animal were found in the areas of heaviest pollution (Figure 21). Numbers of species and numbers of individuals of the bottom animal (Figure 22) followed similar trends with respect to me another and with respect to animal tissue displacement volumes except along the mid-bay transect (Transect II). It seems possible that the relatively large number of species found along this transact is related to the sharp rise in silt content of the muds along this Transect (Figures 23). Such a possibility emphasizes the importance of concurrent studies of bottom materials together with organisms found there.

Conclusions: Bottom animals and plants, together with bottom materials, show marked changes respect to pollution. No plants and few animals were found In areas of heaviest pollution. Immediately outside such areas, bottom animals showed sharp increases, these maxima tapering off roughly in proportion to the gradual appearance of bottom plants. Detailed bottom studies are the most promising of all parameters studied. Data on bottom materials are indispensable to interpretation of population distribution.

Marine Borer Attack Rate. This shows a sharp decline eastward from downtown Miami with the important exception that Station 610 (off Fisher Island, near Quarantine Station) was the highest producing station. Here, panels were exposed in relatively deep water (about 20 feet), in an area with little current activity and with an abundance of old pilings nearby. The writer speculates that the borer attack rate reported in this study is largely dependent on the effectiveness of local larval sources, sewage being an indirect and relatively minor factor.

Conclusions: No conclusive evidence of the effect of sewage pollution on marine borer attack rate was founds this parameter seemingly being more dependent on the advection of larvae than on pollution factors in Biscayne Bay.

Commercial Fisheries. Fisheries personnel of this laboratory with a thorough knowledge of local conditions advise a careful study immediately after sewage is no longer emptied into the Bay. The present condition of the fishery is known with fair accuracy. Good data from past years is available for comparison with future changes in the fishery, if they take place. Trawls in polluted areas yielded few fish, an insufficient number for quantitative purposes.

Conclusions: A study of the future condition of the Biscayne Bay Commercial fishery after pollution ceases to be a factor could provide an index of the effects of pollution on commercially important species.

Future Work. Aside from lack of data from future surveys after pollution has had time to decrease, there are certain aspects of the present survey which are still incomplete and which definitely call for further work. From the hydrographic aspect, there are in hand the data necessary for a thorough analysis of the flushing process in the area. These data have been only tentatively outlined here and full statistical analysis should definitely be made. The understanding of circulation and flushing in Biscayne Bay will have wide application.

From the chemical standpoint, certain stations should be examined at intervals for a further year to confirm the assumption that conditions were reasonably typical during the period of the survey.

Further bacteriological work is clearly called for on the mortality of sewage bacteria in a marine environment.

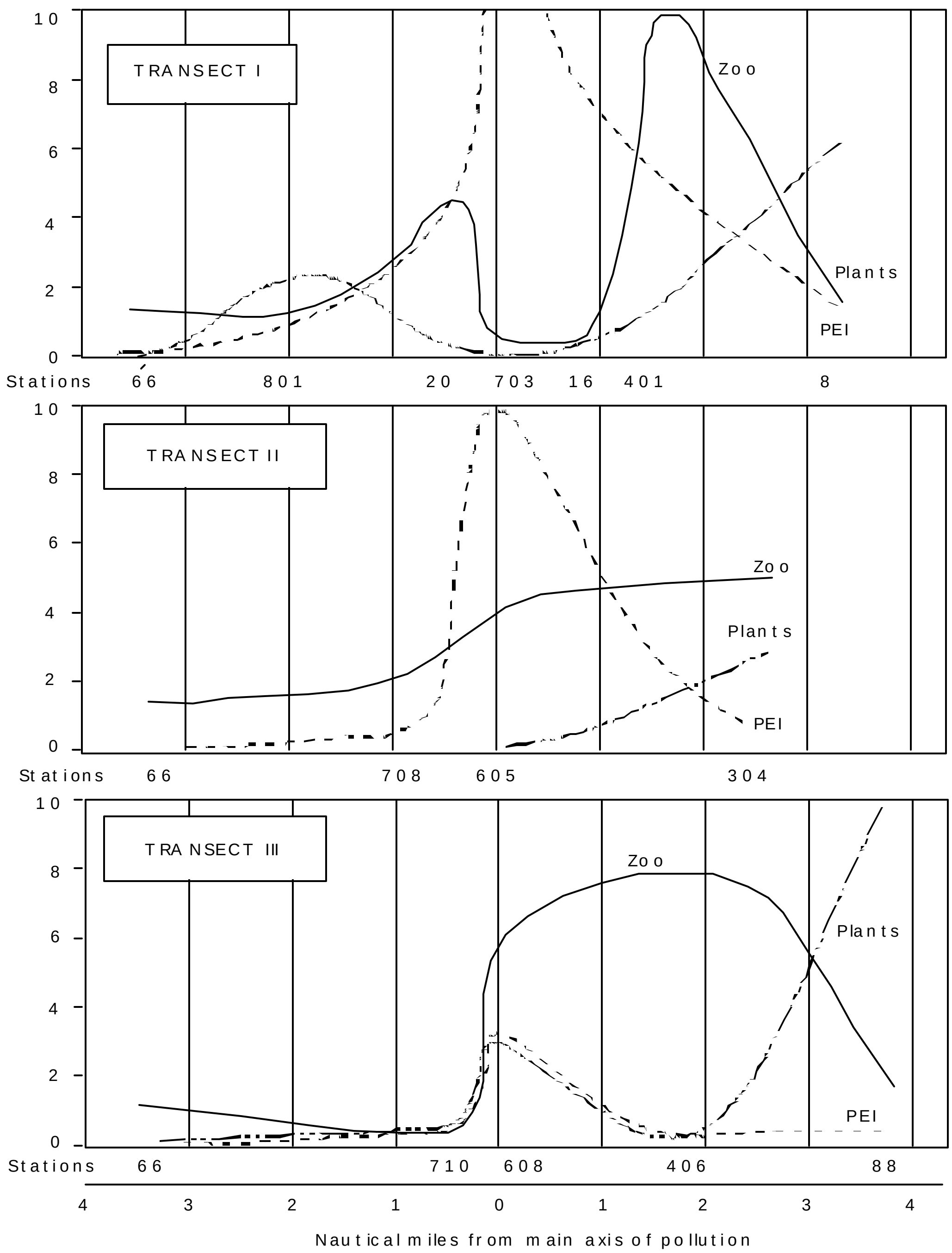

Figure 21. Bottom animals, bottom plants and Pollution Effectivity Index. Displacement volumes of bottom animals (Zoo) and bottom plants (Plants) are compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	Animal vol.	Plant vol.
10	2058	100.4 mL	472.5 mL
0	0	6.5 mL	0.0 mL

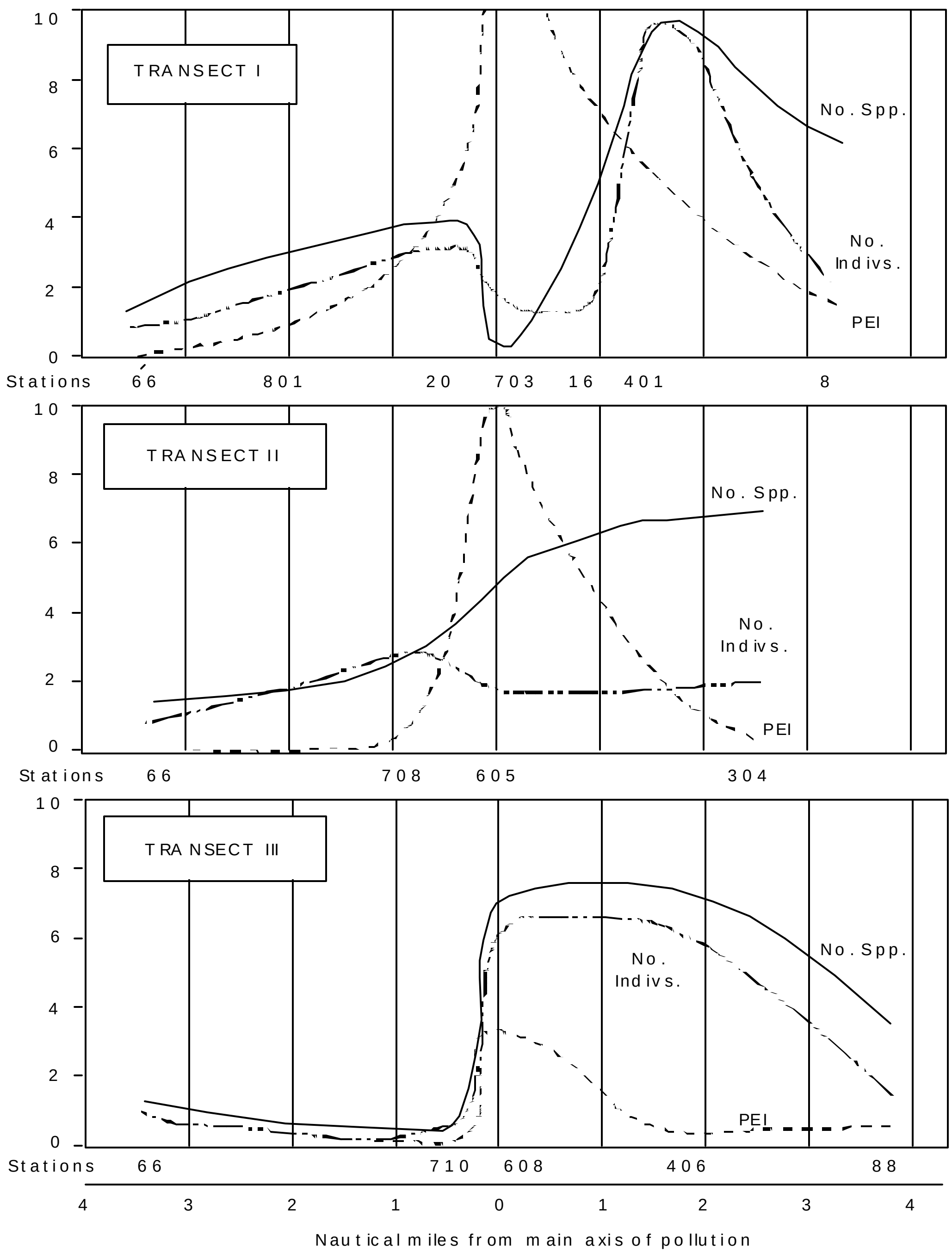

Figure 22. Number of species (No. Spp.) and number of individuals (No. Indivs.) per m^2 of bottom animals, compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	No. Spp.	No. Indivs.
10	2058	26	369.9
0	0	3	16.2

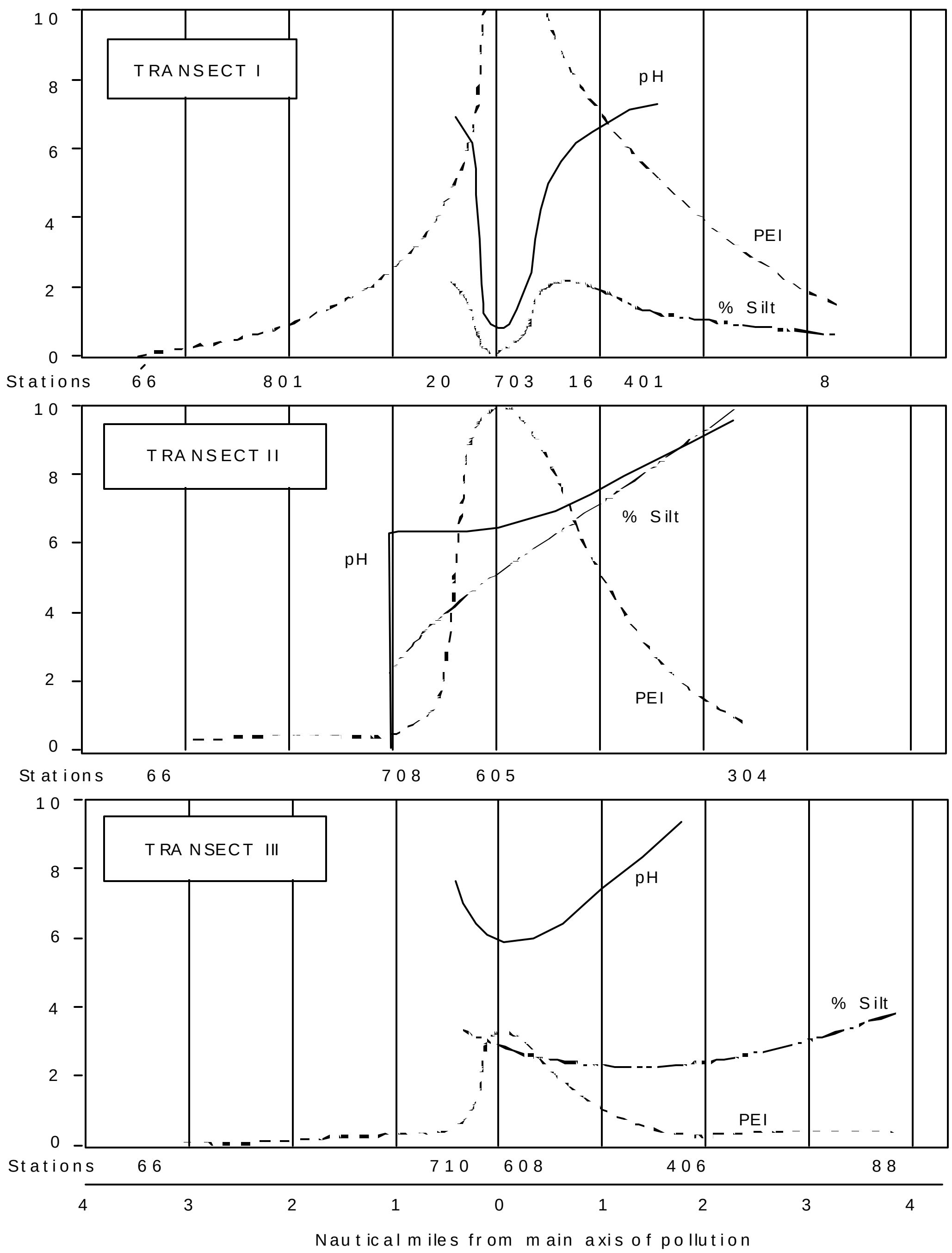

Figure 23. Per cent silt and pH of bottom materials compared with the Pollution Effectivity Index (PEI), scaled as follows:

Scale	PEI	% Silt
10	2058	100
0	0	0

Much of the biological material, particularly the bottom and fouling organism has been only partially identified. Obviously, this must be completed. It will add to the completeness of the picture, is necessary for comparative purposes in future surveys, and may yield indicator species of values. It should be emphasized that an attached form such as an alga, living for a reasonably long life span in a given locality, could be the best integrator of the fluctuating conditions there.

It should also be emphasized that this is a report on work still in progress. It has already afforded a valuable general picture of conditions existing at present and it is possible to make it much more valuable when certain limited aspects have received further work.

VI. CHEMICAL CONSIDERATIONS

Hilary B. Moore

"Pollution" is a term whose meaning depends entirely on the point of view of the worker concerned. From the Public Health point of view, it must be measured in terms of the direct resultant or potential danger to human health (i.e., by certain bacteria), or indirectly by the rendering unsafe of potential human food (i.e., oysters, etc.). Less immediately of concern to human health, but affecting the populations may be the production of bad odors, silting of bathing beaches, harbors, and so forth. There may be other aspects of pollution as well. Reduction of oxygen content may block migrations of fishes. Changes in the nature of the bottom may modify fisheries. Pollution may modify fouling of vessels and attack of both vessels and wooden pilings by borers. These are only a few of pollution's many aspects. Furthers chemical pollution may be of major importance in one case, but sewage pollution in another.

Because of this complexity, it is not to be expected that any one measure of pollution will satisfy all those who are concerned with the phenomenon. Bacterial counts, indicator species, or any other parameter alone cannot be expected to give a complete picture. For this reasons the present study has embraced as many parameters, as possible.

In the preceding sections an attempt has been made to correlate as many observed parameters as possible. Although correlations emerged such as those between PEI, nutritional elements and plankton, the correlations are not close. It is the object of the present theoretical approach to show some of the complexity of the dynamics of the bacterial population and to indicate why closer correlations should not be expected in the present state of our knowledge.

The following mathematical approach is similar to that of Riley* *et al.*, (1949) in which equations for the regional and seasonal distribution of oceanic plankton are developed.

Consider a point (n) relative to a point seaward from it (n-1) and one landward from it (n+1).

Let the bacterial populations at these be P_n, $P(_{n-1})$ and $P(_{n+l})$, respectively.

The population at (n) can increase by the following:

a. recruitment from (n-l) and (n+1)
b. multiplication at (n)
c. addition from sediments due to turbulence.

The population at (n) can decrease by the followings:

d. loss (negative recruitment) to (n-1) and (n+1)
e. removal by plankton which eat it
f. removal by attached fauna which eat it
g. adsorptioin on solid matter
h. mortality in situ due to toxicity of sea water

If P remains unchanged after one tidal cycle, then gain and loss must be equal, as follows:

$$a + b + c = d + e + f + g + h \qquad (1)$$

Assuming that a given volume (V) at (n) exchanges (V_{n-1}) each tidal cycle with the water at (n-1), and (V_{n+1}) with the water at (n+1), and if we assume a mixing factor (x) such that 1/x of the water at (n) is exchanged on each tidal cycle, then the volume exchanged with (n-1) is as follows:

$$(V_{n-1}) = \frac{V}{X}\frac{V_{n-1}}{V_{n+1}} \qquad (2)$$

The water exchanged with (n+1) is as follows:

$$(V_{n+1}) = \frac{V}{X}\left(1 - \frac{V_{n-1}}{V_{n+1}}\right) \qquad (3)$$

Knowing the salinities at (n-1), (n) and (n+1), one can obtain the ratio of (V_{n-1}) to (V_{n+1}) in the total interchanged water as follows:

$$\frac{V_{n-1}}{V_{n+1}} = \frac{S_n - (S_{n+1})}{(S_{n-1}) - S_n} \qquad (4)$$

It is possible that this could be expressed in terms of a parameter other than salinity. If P is used, the equation becomes the following:

* Riley, Gordon A., Henry Stommel and Dean F. Bumpus, 1949. Quantitative ecology of the plankton of the western North Atlantic. Bull. Bing. Oc. Coll., 12(3):1-169.

$$\frac{V_{n-1}}{V_{n+1}} = \frac{P_n - P_{n+1}}{(P_{n-1}) - P_n} \tag{5}$$

It should be instructive to compute the ratio both ways, since any discrepancy might give a lead on what is happening to the pollutants as a result of controlling biological or physical factors.

Item (b) may be non-existent, but if there is any multiplication of the bacteria, it is assumed that this decreases with increased salinity, as follows:

$$b = f\, S \tag{6}$$

If it is assumed that the relationship is linear, then:

$$b = K_b\,(100 - S_n) \tag{7}$$

where K_b is a constant related to bacterial population growth.

Addition from the sediments due to turbulence may follow the relationship indicated below, in which B_p = the bottom bacterial content, W = weather, Ex - exposure of the locality and T = texture of the sediments:

$$c = (f\, B_p \bullet f\, W \bullet f\, Ex \bullet f\, T) \tag{8}$$

It is assumed that the zooplankton which feed directly on the bacteria are all nannoplankton. These reproduce rapidly, so no time delay need be introduced in the bacteria-nannoplankton relationship. From guesses which can be made about nannoplankton nutrition, let it be assumed that their growth, "e", is an function of the following factors:

1. dissolved organic matter
2. particulate organic matter
3. salinity
4. pH (a low pH may favor)
5. temperature (a high temperature may favor)

Then, if Z_0 = zooplankton, and K is a grazing constant, these factors may be equated as follows:

$$e = Z_0 \bullet K_z \bullet f\, Z_1 \bullet f\, Z_2 \bullet f\, Z_3 \bullet f\, Z_4 \bullet f\, Z_5 \tag{9}$$

The attached, bacteria-eating fauna, should be distinguished from the fauna which are not bacteria feeders. The former should be divided into "unprotected" and "protected" forms. The unprotected are in contact with the environment at all times. and may be assumed to feed all of the time. The protected can close their shells, or other protective devices, and isolate themselves from the environment for many part of the tidal cycle. In so doing, the reduce their feeding period and hence their growth rate. Protected bacteria feeders are designed as B_p and unprotected bacteria feeders are B_u.

Modifying factors might be the following:

1. temperature
2. salinity
3. toxicity
4. food (particulate and dissolved organic in addition to bacteria)

If K_{B_p} and K_{B_u} are growth constants and C is the per cent of the tidal cycle during which the protected forms stay closed, the following reasoning may apply:

$$\text{feeding of } B_p = K_{B_p} \bullet f\,\text{Temp} \bullet f\,\frac{C}{100} \bullet f\,\text{food}, \tag{10}$$

$$\text{feeding of } B_u = K_{B_u} \bullet f\,\text{Temp} \bullet f\, S_n \bullet f\,\text{tox} \bullet f\,\text{food}, \tag{11}$$

and

$$f = \text{the sum of (10) and (11)} \tag{12}$$

Adsorption will be the function of surface area. This may be conveniently divided into the following:

1. bottom area and pilings, etc.
2. area of attached organisms
3. sedimentation (removing bacteria from the water and depositing them on the bottom)

If A_B = bottom area, A_0 = organisms, and sedimentation rate = A_S, then the term "g" may be expressed as follows:

$$g = (f\ A_B + f\ A_0 + f\ A_S) \tag{13}$$

Mortality due to toxic action of sea water may be presumed to be a function of the salinity, expressed as follows:

$$h = f\ S_n \tag{14}$$

Since equation (1) was the following:

$$a + b + c = d + e + f + g + h \tag{1}$$

a general statement incorporating all of the foregoing can be made, as follows:

$$\underbrace{(P_{n-1})\ (1/x) : \frac{S_n - (S_{n+1})}{(S_{n-1}) - S_n} + (P_{n+1})\ (1/x)\ (1 - \frac{S_n - (S_{n+1})}{(S_{n-1}) - S_n}}_{= \text{a (derived from Eq. 4)}} + \underbrace{K_b\ (100 - S_n)}_{= \text{b (Eq. 7)}} +$$

$$\underbrace{f\ B_p \cdot f\ W \cdot f\ Ex \cdot f\ Temp}_{= \text{c (Eq. 8)}} =$$

$$\underbrace{(P_n)\ (1/x) \cdot \frac{S_n - (S_{n+1})}{(S_{n-1}) - S_n} + (P_n)\ (1/x)\ (1 - \frac{S_n - (S_{n+1})}{(S_{n-1}) - S_n}}_{= \text{d (Eq. 4)}}$$

$$\underbrace{Z_0 \cdot K_B \cdot f\ Z_1 \cdot f\ Z_2 \cdot f\ Z_3 \cdot f\ Z_4 \cdot f\ Z_5}_{= \text{e (Eq. 9)}} +$$

$$\underbrace{K_{B_p} \cdot f\ Temp \cdot f \frac{C}{100} \cdot f\ food + K_{B_u} \cdot f\ Temp \cdot f\ Sn \cdot f\ tox \cdot f\ food}_{= \text{f (Eq. 10, 11)}} +$$

$$\underbrace{(f\ A_B + f\ A_0 + f\ A_S)}_{= \text{g (Eq. 13)}} + \underbrace{f\ S_n}_{= \text{h (Eq. 14)}} \tag{15}$$

A solution to equation 15 cannot be computed, since many more parameters are used in the equation than were measured in the field. The equation does emphasize points on which data are urgently needed if the dynamics of coliform bacteria populations are to be understood. It also serves to show why a high correlation cannot be expected between such factors as P and S, for example.